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A historical review of promotion strategies for electricity from renewable energy sources in EU countries

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ABSTRACT

The core objective of this paper is to elaborate on historically implemented promotion strategies of renewable energy sources and the associated deployment within the European electricity market. Hence, at a first glance, the historic development of renewable energy sources in the electricity (RES-E) sector is addressed on Member State and on sectoral level as well as consequently discussed according to available RES-E potentials and costs.

The specific focus of this paper, are promotion strategies for RES-E options as they are the key driver of an efficient and effective RES-E deployment. Therefore, the paper depicts the main types of different promotion schemes and their properties. Additionally, several cases studies of different European Member States show an in-depth analysis of the different RES-E promotion schemes. In this context, special emphasises are put on the question of effective and efficient promotion scheme designs of different RES-E technologies. Generally, conducted research led to the conclusion, that technology specific financial support measures of RES-E performed much more effective and efficient than others did. Hence, it is not all about the common question of feed-in tariffs vs. quota systems based on tradable green certificates, but more about the design criteria of implemented RES-E support schemes.

Contents

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1. Introduction

1.1. Motivation: EU-targets for RES

Increasing the share of renewable energy for electricity generation (RES-E) is a major target within the European Union as well as at global scale. In 2001 the Directive 2001/77/EC [4] on renewable energies in the electricity sector (European Parliament and Council, 2001) set challenging indicative national targets to increase the share of RES-E in the EU electricity mix from 12% in 1997 to 21% by 2010. A more recently accepted target is to strive for an increase of the share of renewable energy sources (RES) in overall EU energy consumption from 8.5% today to 20% by 2020. Corresponding national targets have been proposed by the European Commission in the Directive on the promotion of the use of energy from renewable sources (COM(2008) 19) [5] as integral part of the climate and energy package of 23 January 2008. In contrast to prior, national targets are now referring to all energy sectors (and not only the power sector) and are legally binding.

Yet, to bring about a breakthrough for RES, a series of barriers have to be overcome and proper promotion strategies have to be implemented. Currently, a wide range of strategies is applied in different countries. Yet, which of the different instruments is most effective and efficient for increasing the dissemination of RES-E is still a topic of very controversial discussions. Within the wide range of applicable strategies most important is the discussion whether feed-in tariffs or tradable green certificates based on quotas are preferable.

1.2. Objective of this paper

The major objectives of this report are to:

- document the development of the RES-E market in the EU-27 in recent years;
- describe which energy policy instruments have been applied and consequently resulted in specific deployments;
- provide a brief evaluation of the performance of various strategies in the last years within the EU Member States. Thereby, the economic efficiency (e.g. costs per kWh new RES-E) and the effectiveness (e.g. kW deployed per year and capita) of different support instruments like quota systems based on tradable green certificates (TGCs), tenders or feed-in tariffs (FITs) are depicted at Member State level.

1.3. Review of the literature

In the literature, reviewing the effectiveness and efficiency of various promotion strategies for RES-E has attracted increasing attention in recent years. Thereby the impact of the design of direct policy instruments on the market growth and on the policy costs of different support measures have been in the focus of the discussion. Yet, although it has increased substantially, the impact of deregulation and competition on renewables were often neglected. As a starting point, the wide range of schemes to promote RES is e.g. described by Haas et al. [6].

One of the first survey papers was published by Meyer [13]. Therein, he concludes that the big challenge for the proponents of market principles is to demonstrate that the dilemma of striving for short-term profits on the one hand and aiming for long term investments and cost reductions on the other hand can be solved satisfactorily. Huber et al. [11] give a concise summary of comprehensive effects of different design elements of renewable energy policy instruments. Their major conclusions are that the careful design of strategies is by far the most important aspect and that the promotion of newly installed plants rather than already existing plant is crucial for a successful strategy. Moreover, they argue that so far well-designed FITs were more effective and cost-efficient than other promotion schemes.

van der Linden et al. [18] discuss the success of renewable energy obligation support mechanisms in Europe and the U.S. Their major conclusion is that "a [TGC-based] obligation is effective and cost-effective in theory. However, it seems too early to conclude that the system delivers these promises in practice".

An analysis carried out by Dinica [3] examines the diffusion of renewable energy technologies taking into account the role of investors. She argues that a sound and secure investment climate which allows sufficient profitability combined with low investment risks is vital for a significant development of RES-E. Lemming [12] scrutinises financial risks in a TGC market and concludes that the higher risks associated with TGC-systems compared with FIT-systems result in higher profit requirements by investors.

Mitchell et al. [15] compare the UK quota obligation system with the German FIT system regarding the correlation between risks for generators or investors and policy effectiveness. They come to the conclusion that low risks implicate high policy effectiveness and that the German FIT-system provides higher security for investors than the British Renewables Obligation. Butler and Neuhoff [1]

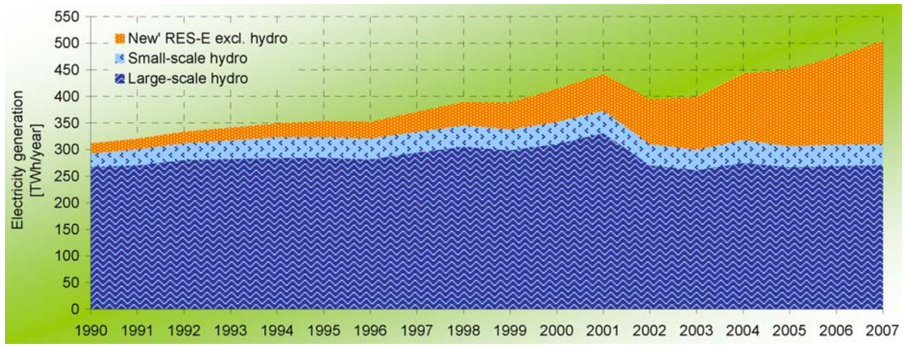


Fig. 1. Historical development of electricity generation from RES in the European Union (EU-27) from 1990 to 2007.

conclude that the "resource-adjusted costs to society of the FIT is currently lower than the cost of the TGC systems".

Held et al. [10] and Ragwitz et al. (2007) [16] analyse the success of policy strategies for the promotion of electricity from renewable energy sources in the EU. They show that instruments, which are effective for the promotion of RES-E are frequently economically efficient as well. Furthermore they conclude that "promotion strategies with low policy risks have lower profit requirements for investors and, hence, cause lower costs to society".

Toke [17] assesses the effectiveness of the UK's Renewable Obligation (RO). He concludes that "there are problems with the British RO, and it certainly does not deliver renewable energy any more cheaply than a feed-in tariff."

Haas et al. [7] compare different promotion schemes for RES-E world-wide. Their major conclusion is that "promotional schemes that are properly designed within a stable framework and offer long-term investment continuity produce better results."

Finally, in a recent paper Meyer [14] analyses the major lessons learned from wind energy policy in the EU: Lessons from Denmark, Sweden and Spain. His major conclusion is that "the lack or delayed development of such a supportive, stable environment explains the different patterns of wind development seen in Sweden and Spain" and points to the problems created by liberalised and short-sighted commercial energy markets even for wind energy pioneers like Denmark.

2. Historical development and current status of RES-E deployment in EU countries[1]

2.1. Historical development at EU level

The historical development of electricity generation from RES at EU-27 level is shown in Fig. 1 for the period 1990 to 2007, whereby total RES-E generation grew by 30% from 371 TWh in 1997 to 503 TWh in 2007. As observable therein, hydropower is the dominant renewable energy source, comprising about 90% of all RES-E production in 1997. However, this dominance has been slowly decreasing over the past years. Reasons for this are twofold: On the one hand, actual rainfall was below average in some years, especially in the near past (from 2002 to 2007). On the other hand, a continuous growth of 'new' RES-E[2] such as wind or biomass has been taking place. In 2007 hydropower contributed only 60% to total RES-E generation in the EU-27.

The share of RES-E in gross electricity consumption was 14.1% in 2007 at EU-27 level. Compared to 1997 when RES-E accounted for 12.8% this represents only a marginal increase, despite positive developments regarding 'new' RES-E. Two issues are of importance in this respect: Firstly, the contribution of hydropower in 2007 was lower than in 1997 due to below average rainfall, which strongly affects the overall RES-E generation figure. Assuming normal climatic conditions, the contribution of RES-E as a share of electricity consumption in 2007 would have been 14.9%. Secondly, the demand for electricity at EU level has grown by more than 15% since 1997, which has largely offset the newly realised deployment of RES-E since then. If electricity consumption would have remained at 1997 levels, the actual contribution of RES-E in 2007 would have been 17.4%. Taking additionally also normal climatic conditions into account, the RES-E share in 2007 would have been 18.5%.

More detail of the development of 'new' RES-E is given in Fig. 2, expressing the evolution of electricity generation at EU27 scale on technology level excluding hydro power, again for the period 1990–2007. As observable, biomass and wind power are mainly responsible for the impressive historic progress, especially in recent years (from 1997 on).

Below Fig. 3 illustrates the corresponding yearly growth rates of the individual 'new' RES-E technologies. However, care should be taken when interpreting these results, since growth rates may easily be higher for any novel technology option in an early stage of market development compared to a mature one.

A comparison of the deployment of 'new' RES-E technologies within two differing time periods – i.e. 1990–1998 and 1999–2007 – is given in Fig. 4. Although a strong development of onshore wind and biomass energy was dominating in both time periods, the major share of small-scale hydro power plants in early years was substituted by wind onshore energy in the more recent past. However, recently also an expansion of photovoltaics is getting apparent. In contrast to above, biowaste expanded mainly in the early years.

2.2. Progress at country level

Fig. 5 depicts the share of RES-E in total electricity consumption for the years 1997 and 2006. Additionally, this depiction indicates the indicative national RES-E targets for 2010 as set by Directive 2001/77/EC [4]. It is getting apparent that in particular Denmark, Germany, Hungary and Slovenia were able to increase their RES-E share considerably during the considered period. Comparing the RES-E share of the mentioned countries in 2006 to the given targets, a fulfilment can be expected assuming a constant future growth of RES-E exploitation. By contrast an increase in gross electricity consumption in combination with considerable restraints of the

[1] As default data as presented in this chapter is based on EUROSTAT – for the exceptional case where alternative data proved to be more accurate, the default data was modified. For 2007 only provisional data was applicable for some technologies, which is then based on IEA and EurObserver.

[2] The technologies assessed include hydropower (large and small), photovoltaic, solar thermal electricity, wind (onshore, offshore), biogas, solid biomass, biodegradable fraction of municipal waste, geothermal, tidal and wave energy.

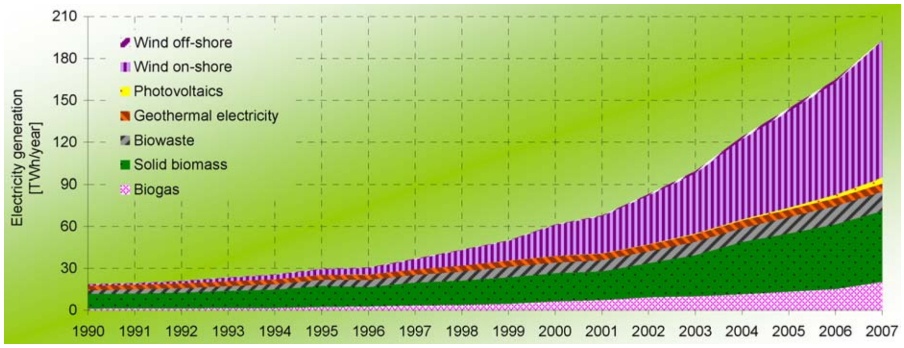


Fig. 2. Historical development of electricity generation from 'new' RES (excl. hydro) in the European Union (EU-27) from 1990 to 2007.

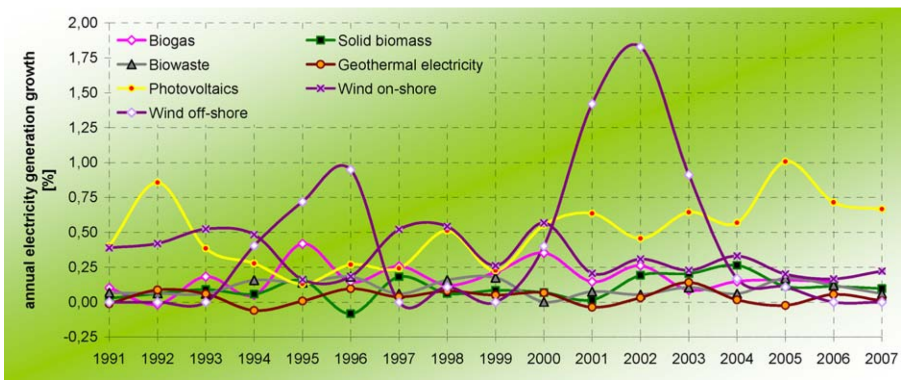


Fig. 3. Historical development of electricity generation from 'new' RES and annual growth rates in the European Union (EU-27) from 1991 to 2007.

diffusion of RES-E resulted even in a decrease of the RES-E share in Austria, France and Portugal. Although a fulfilment of 2010 RES-E targets appears almost impossible, those countries have to take major efforts on both the supply (i.e. the RES-E support) and the demand-side (i.e. to slow down or even reverse demand growth) in order to get back on the required trajectory.

Next the contribution of individual RES-E technologies is assessed at country level. In Fig. 6 the countries are ranked by

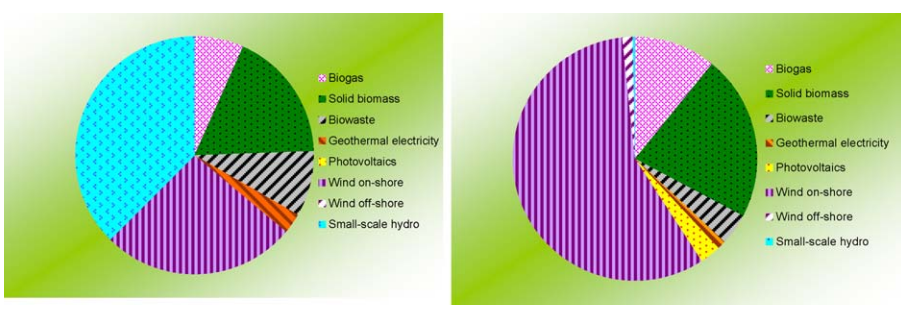


Fig. 4. Historical development of electricity generation from 'new' RES-E sources sorted by source and separated in the period from 1990 to 1998 (left side) and from 1999 to 2007 (right side).

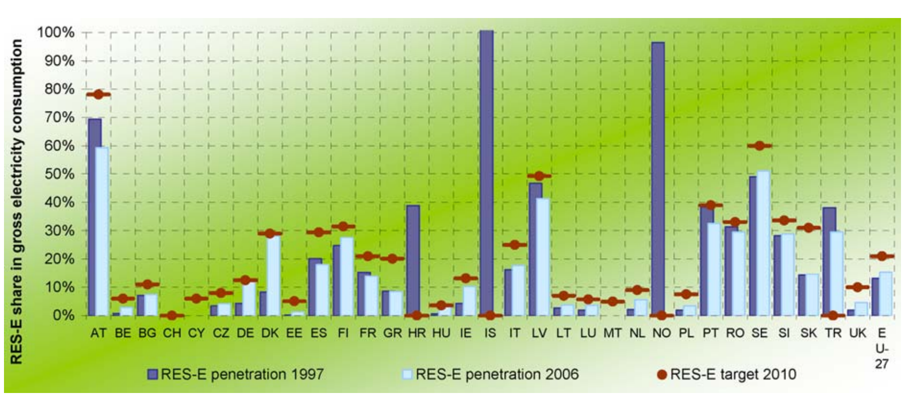


Fig. 5. RES-E share (incl. large hydro) in gross electricity consumption in the EU countries in 1997 and 2006 and the targets for 2010.

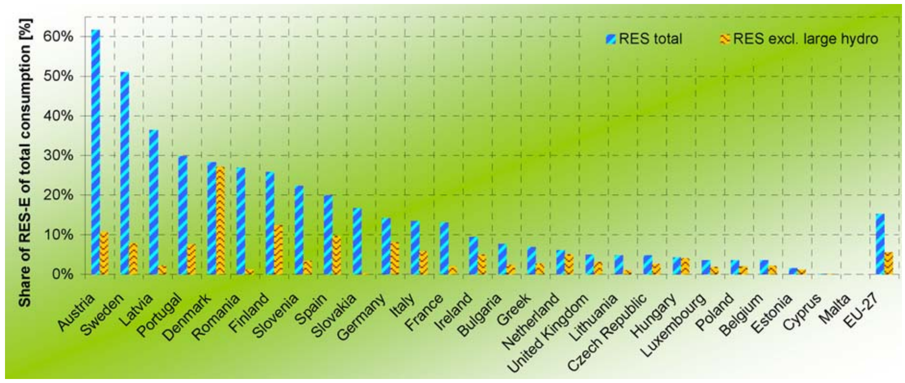


Fig. 6. RES-E share and share exclusive large hydro in gross electricity consumption in the EU countries in 2007.

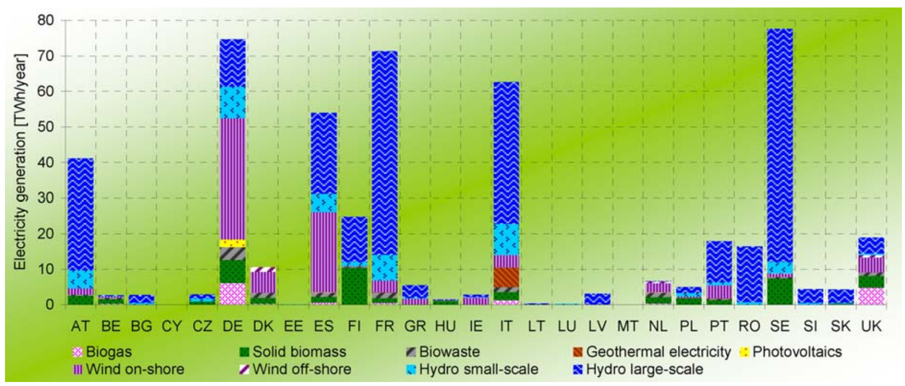


Fig. 7. RES-E generation in 2007 by EU-27 Member State.

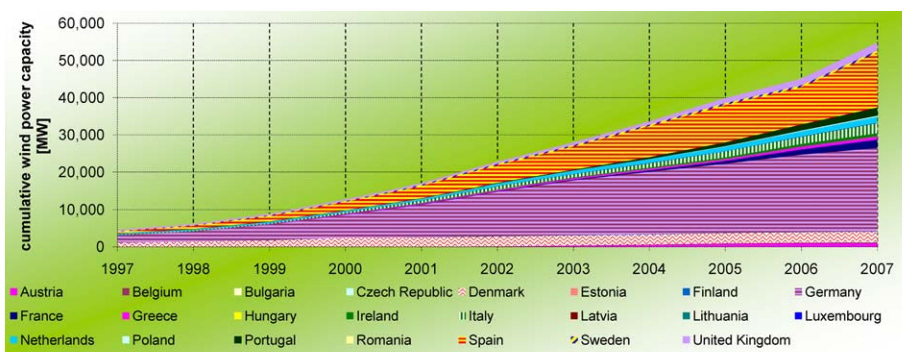


Fig. 8. Historical development of cumulative installed wind capacity in EU-27 countries.
Source: EWEA, IEA Renewables Information 2007.

their RES-E share neglecting or considering the contribution of large hydropower. At present within four countries, namely Austria, Sweden, Latvia and Romania, more than a third of their overall electricity demand is met by RES-E (including large hydro) generation.

The deployment of RES-E at country level is illustrated in Fig. 6 for the year 2007. Again it can be seen that small hydro, biomass, and wind are the most important at present.

Of interest, are (i) the large proportions of wind power in Denmark, Spain, and Germany, (ii) the significant contribution of geothermal power in Italy, and (iii) high proportion of power generated from biomass in the UK (including landfill gas, municipal waste and sewage gas), Finland, Sweden and Germany, see Fig. 7.

2.3. Technology details: the evolution of wind power and biomass

Onshore wind power has been the most successful RES technology in recent years, see Fig. 2. Figs. 8 and 9 depict the specific development of onshore wind power in selected EU countries although it needs to be mentioned that installations of new onshore wind capacity in Denmark have been close to zero in the recent past. This is mainly caused by policy change in the new Danish RES legislation. The new policy relies mainly on the market forces to drive the development.

However, due to rising prices of row materials as steel, investment costs of wind mills increased and consequently the installed wind capacity stagnated or even decreased slightly within the recent years since support scheme have not been adjusted accordingly, see Fig. 9. Additional to increasing investment costs, financial incentives for wind energy have not been high enough in order to stimulate a constant capacity growth rate as in earlier years. In contrast, other countries as the United Kingdom, France or Portugal set efficient measures for recently, tremendous wind installations.

As Fig. 4 shows, biomass has the second largest percentage of renewable electricity generation in the EU-27. The biggest shares

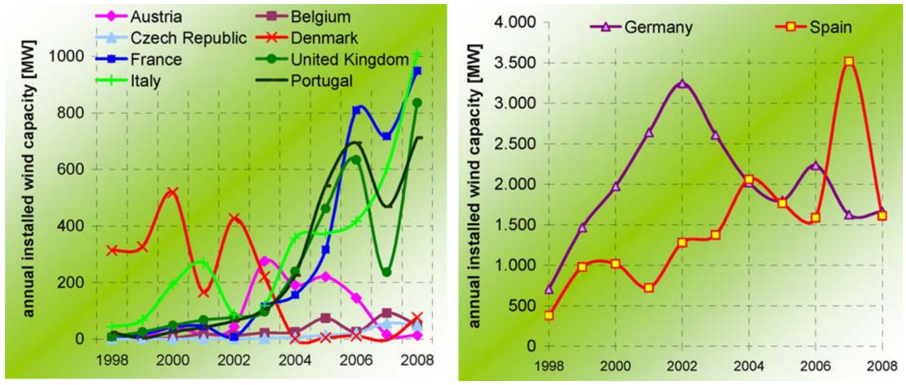


Fig. 9. Historical development of annual installed wind capacity in selected EU countries.
Source: EWEA, IEA Renewables Information 2008.

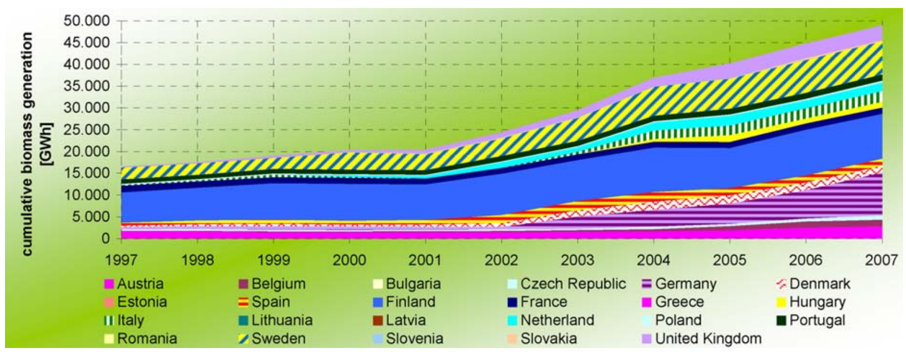


Fig. 10. Historical development of cumulative installed biomass capacity in EU-27 countries.

Source: Eurostat 2008.

hold Sweden and Finland, whereby recently RES-E generation from biomass increased in Denmark, Italy and the United Kingdom, see Fig. 10. A strong future increase of cumulative biomass capacity is expected due to large potentials in the new EU Member States.

Fig. 11 shows the cumulated installed biomass capacity in selected EU countries. Generally in contrast to the wind energy sector a more uniform growth is observed due to less sensitive investment costs and continuous financial support schemes. However, in the year 2001 some plants in Germany were decommissioned that are only slightly replaced by new biomass technologies.

3. Potentials achieved and remaining by country and technology

In the following the potentials achieved and remaining by country and technology are depicted. The future potentials were assessed taking into account the country-specific situation as well as realisation constraints. Fig. 12 depicts the achieved and additional mid-term potential for RES-E in the EU-15 by country (left-hand side) as well as by RES-E category (right-hand side). A similar picture is shown for the new member states (EU-12) and selected candidate countries in Fig. 13. For EU-15 countries, the already achieved potential for RES-E equals 468 TWh,[3] whereas the additional realisable potential up to 2020 amounts to 945 TWh (about 38% of current gross electricity consumption). Corresponding figures for the EU-12 are 42 TWh for the achieved potential and 145 TWh for the additional mid-term potential (about 36.1% of current gross electricity consumption).

The country-specific situation with respect to the achieved as well as the future potential shares of available RES-E options is depicted below in more detail. Fig. 14 indicates the share of the various RES-E in the achieved potential for each EU-15 country. As already mentioned, (large-scale) hydropower dominates current RES-E generation in most EU-15 countries. However, for countries like Belgium, Denmark, Germany, the Netherlands or the UK – most characterised by rather poor hydro resources – wind, biomass, biogas or bio waste are in a leading position. Fig. 15 illustrates the shares of specific RES-E in the total achieved potential for EU-12 countries: here, hydropower accounts for 87.9% of the RES-E production and, of the other RES-E options, only biomass, biogas and wind were of any relevance. Only in the Czech Republic, Estonia, Hungary and Poland have biomass electricity at shares of 21%, 17%, 83% and 39%, respectively. In all other countries, biomass contributes less than 2% to the RES-E share. In Estonia and Poland, wind energy has attained shares of 56% and 4% in RES-E production, respectively. In this context, also Cyprus has to be mentioned where solely wind energy and photovoltaic dominate the minor renewable energy contribution on electricity supply.

Fig. 16 shows the share of different energy sources in the additional RES-E mid-term potential for the EU-15 for 2020. The largest potential is found in the sector of wind energy (45%) followed by solid biomass (16%), biogas (9%) as well as promising future options such as tidal and wave (13%) or solar thermal energy (3%).

Fig. 17 illustrates the share of different energy sources in the additional RES-E mid-term potential of the EU-12 countries for

[3] The electricity generation potential represents the output potential of all plants installed up to the end of each year. Of course, the figures for actual generation and generation potential differ in most cases – due to the fact that, in contrast to the actual data, the potential figures represent normal conditions, e.g. in case of hydropower, the normal hydrological conditions, and furthermore, not all plants are installed at the beginning of each year.

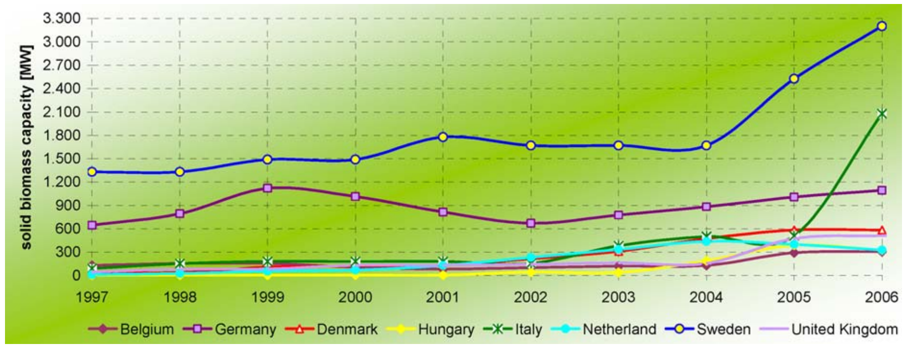


Fig. 11. Historical development of cumulative solid biomass capacity in selected EU countries.

Source: Eurostat 2008.

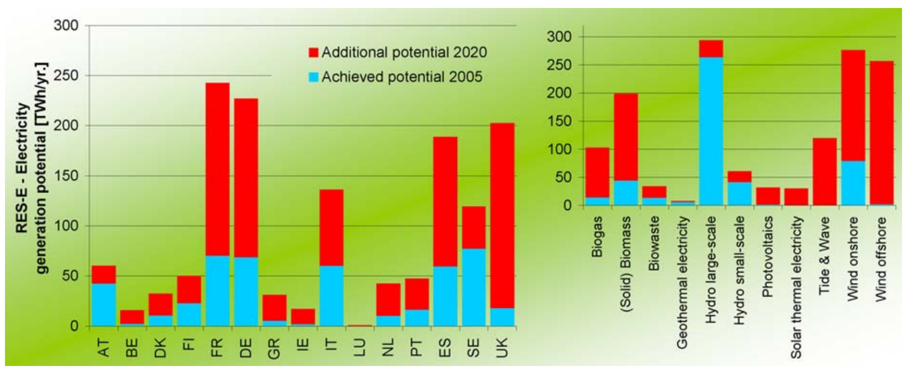


Fig. 12. Achieved (2005) and additional mid-term potential 2020 for electricity from RES in the EU-15 – by country (left) and by RES-E category (right).

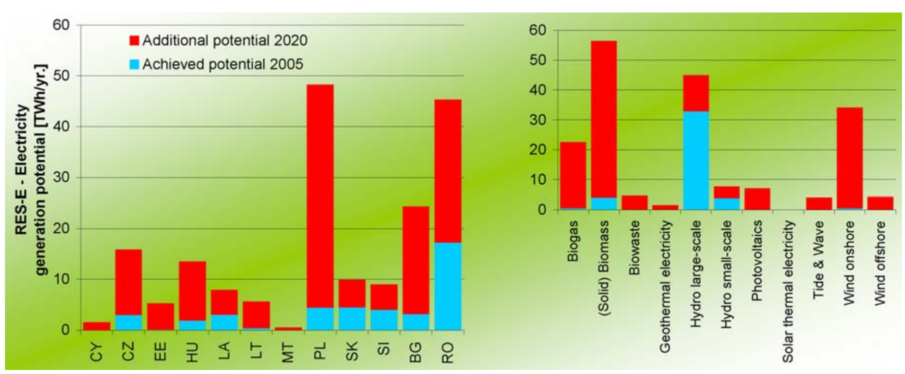


Fig. 13. Achieved (2005) and additional mid-term potential 2020 for electricity from RES in EU-12 countries – by country (left) and by RES-E category (right).

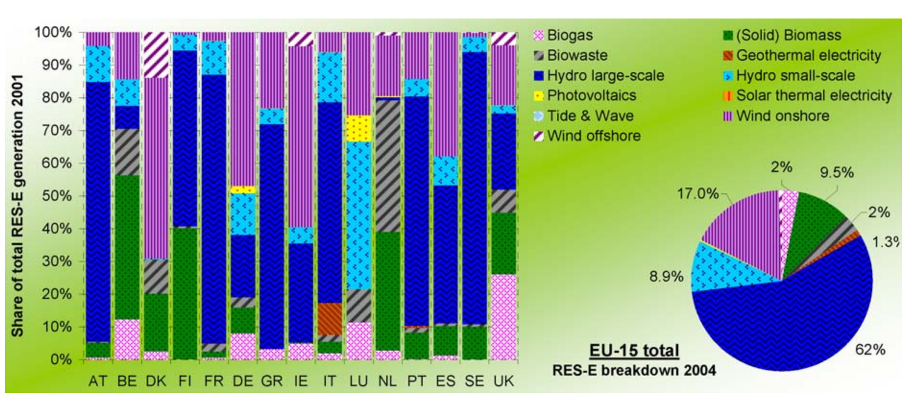


Fig. 14. RES-E as a share of the total achieved potential in 2005 for the EU-15 – by country (left) as well as for total EU-15 (right).

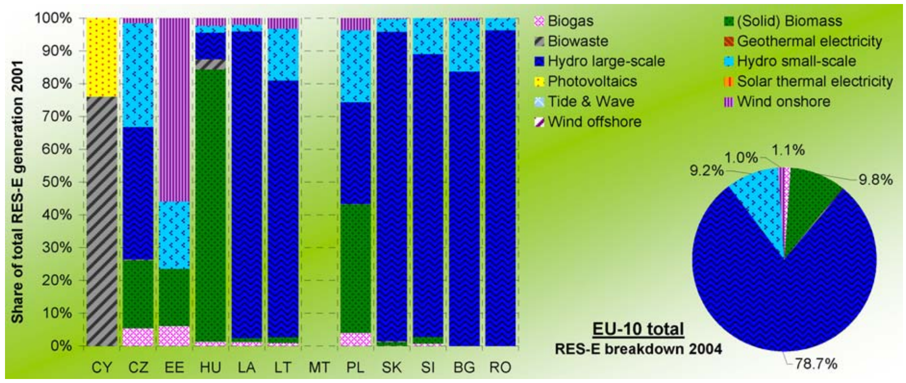


Fig. 15. RES-E as a share of the total achieved potential in 2005 for the EU-12 – by country (left) as well as for total EU-12 (right).

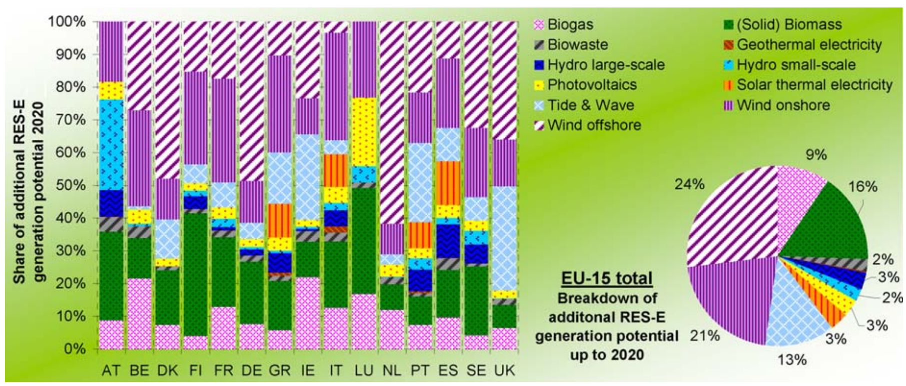


Fig. 16. RES-E as a share of the total additional realisable potential in 2020 for the EU15 – by country (left) as well as for total EU-15 (right).

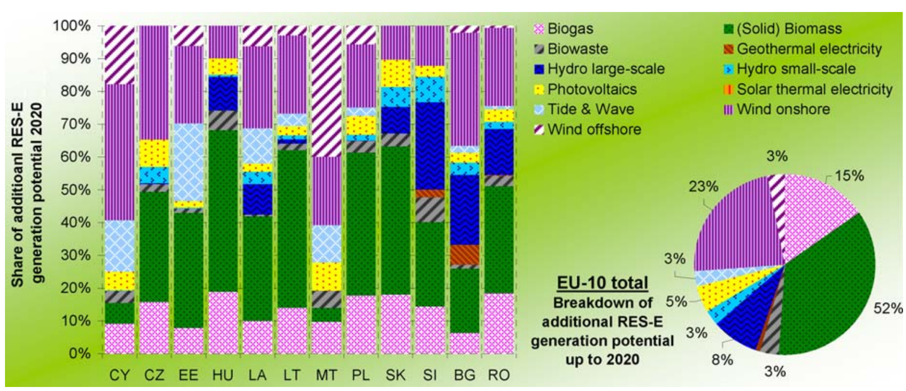


Fig. 17. RES-E as a share of the total additional realisable potential in 2020 for the EU12 – by country (left) as well as for total EU-12 (right).

2020. In contrast to the EU-15, the largest potentials for these countries exist in the sectors of solid biomass (52%) and wind energy (26%) followed by biogas (15%). Unlike the situation in the EU-15, the refurbishment and construction of large hydro plants holds significant potentials (8%).

4. Cost of RE technologies

The broad range of costs for several RES-E represents, on the one hand, resource-specific conditions as are relevant e.g. in the case of photovoltaics or wind energy, which appear between and also within countries. On the other hand, costs also depend on the technological options available – compare, e.g. co-firing and small-scale CHP plants for biomass.

Nevertheless, in order to give a better illustration of the current[4] economic conditions of the various RES-E options, Fig. 18 depicts long-run marginal generation costs[5] by RES-E category. Thereby, for the calculation of the capital recovery factor a default setting, i.e. a payback time of 15 years, is used for all RES-E options – see Fig. 18. Most RES-E technologies are to certain extend already competitive on the power market, whereas this fact is strongly influenced by sitting of the plants as well as by non-economic market barriers.

[4] Generation costs refer to the starting year for model simulations, i.e. 2006 and, hence, are expressed in €2006.

[5] Long-run marginal costs are relevant for the economic decision whether to build a new plant or not. For both cases a default weighted average cost of capital (WACC) in size of 6.5% is used.

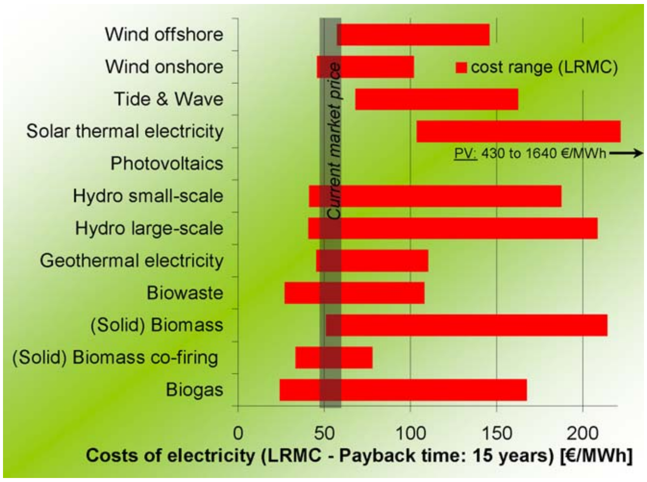


Fig. 18. Long-term marginal generation costs (for the year 2006) of different RES-E technologies in EU-27 countries – based on a default payback time of 15 years.

Of course, of specific interest is future cost development especially due to technological learning forecasting technology development is a crucial activity, especially for a long time horizon. Considerable efforts have been made recently to improve the modelling of technology development in energy models. A rather 'conventional' approach relies exclusively on exogenous forecasts based on expert judgements of technology development (e.g. efficiency improvements) and economic performance (i.e. described by investment and O&M costs). More recently within the scientific community this has often been replaced by technology-based cost dynamics which allow endogenous forecasts, at least to some extent, of technological change in energy models. This approach of so-called technological learning or the experience/learning curves method takes into account the "learning by doing/producing/installing" effect.[6]

Fig. 19 demonstrates the cost development of onshore wind power converters with respect to the installed wind capacity in Denmark. Due to the mentioned technological learning effect a strong decrease in the generation costs is observed in the late eighties.

Furthermore, Fig. 20 depicts the correlation of the specific investment costs of wind turbines and the deployment of the steel price. In recent years a strong impact on the investment costs is noticed due to an intensified demand in the Far East region.

5. Survey on current policies

This section outlines the main policy schemes applied in Europe and includes a classification and characterisation of the schemes.

5.1. Types of policies

A fundamental distinction can be made between direct and indirect policy instruments. In this context, direct policy measures aim at the immediate stimulation of RES-E, whereas indirect instruments focus on improving long-term framework conditions. Besides regulatory instruments, there are also voluntary approaches to the promotion of RES-E, which are mainly based on consumers' willingness to pay premium rates for green electricity. Further important classification criteria are whether policy instruments address price or quantity, and whether they support investment or generation.

Table 1 provides a classification of existing promotion strategies for renewables, with an explanation of the terminology to follow (Menanteau et al., 2004, Haas et al. [8]).

5.1.1. Regulatory price-driven strategies

Generators of electricity from RES receive financial support in terms of a subsidy per kW capacity installed or a payment per kWh produced and sold. The major strategies are:

- Investment focused strategies: financial support is given by investment subsidies, soft loans or tax credits (usually per unit of generating capacity);
- Generation based strategies: financial support is a fixed regulated FIT or a fixed premium (payment per unit of generated energy) that a governmental institution, a utility or a supplier is legally obligated to pay for renewable electricity from eligible generators.

The difference between fixed FITs and premiums is the following. While for fixed FITs the total feed-in price is fixed, for premium systems the amount to be added to the electricity price is fixed. For the renewable plant owner, the total price received per kWh, in the premium scheme (electricity price plus the premium), is less predictable than under a feed-in tariff because it depends on a volatile electricity price.

In principle, a mechanism based on a fixed premium/environmental bonus that reflects the external costs of conventional power generation could establish fair trade, fair competition and a level playing field in a competitive electricity market between RES and conventional power sources. From a market development perspective, the advantage of such a scheme is that it allows renewables to penetrate the market quickly if their production costs drop below the electricity-price-plus-premium. If the premium is set at the 'right' level (theoretically at a level equal to the external costs of conventional power), it allows renewables to compete with conventional sources without the need for governments to set "artificial" quotas. Together with taxing conventional power sources in accordance with their environmental impact, well-designed fixed premium systems are theoretically the most effective way of internalising external costs.

In practice, however, basing the mechanism on the environmental benefits of renewables is challenging. Ambitious studies, such as the European commission's ExternE project, of the external costs of power generation, have been conducted in both Europe and America. It illustrates that establishing the exact costs is a complex matter. In reality, fixed premiums for wind power and other renewable energy technologies, such as the Spanish model, are based on estimated production costs and is a comparison with the electricity price – rather than the environmental benefits of RES.

5.1.2. Regulatory quantity driven strategies

The desired level of generation or market penetration of RES – a quota or a Renewable Portfolio Standard – is defined by governments. The most important points are:

- Tendering or bidding systems: calls for tenders are launched for defined amounts of capacities. Competition between bidders leads to the winners of contracts which will receive a guaranteed tariff for a specified period of time.
- Tradable certificate systems: these systems – in Europe better known as TGC systems, in the U.S. and Japan called renew-

[6] In principle the so-called 'learning effect' – which has been empirically observed in several fields of technological development – states that for each doubling of producing installing a certain technology, a decline of the costs can be expected by a certain percentage, the so-called 'learning rate'. For a brief description of the learning experience curve approach, see e.g. Wene [20].

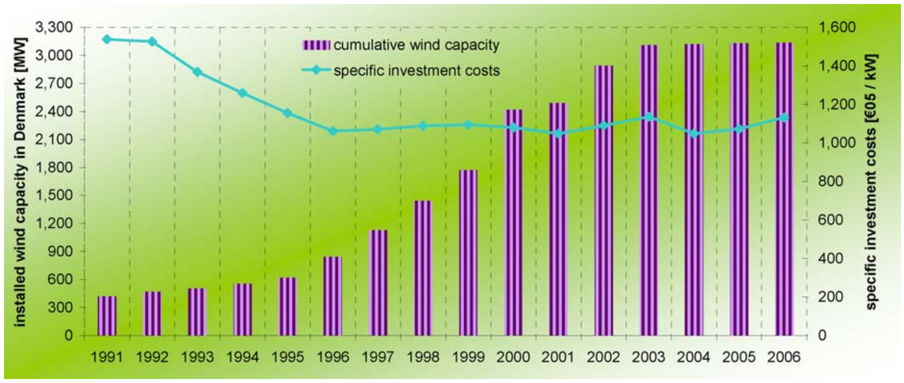


Fig. 19. Deployment of installed onshore wind capacity in Denmark (left scale) and of the corresponding specific investment costs, expressed in Euro 2006 (right scale).

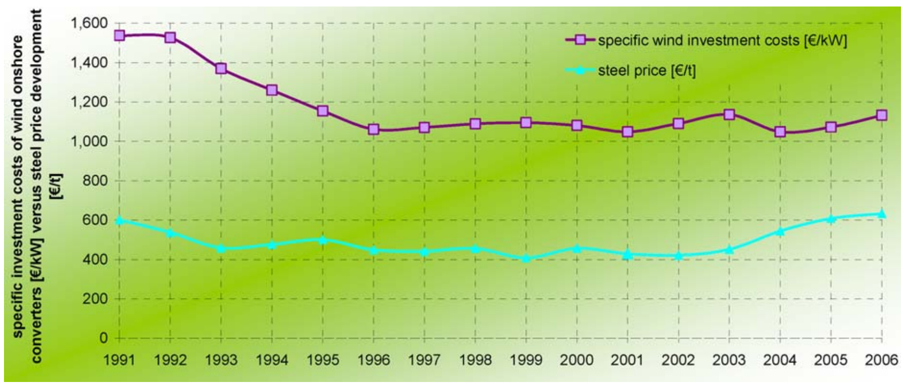


Fig. 20. Comparison of the specific wind investment costs and of the steel price.

Table 1
Fundamental types of promotion strategies.

		Direct		Indirect
		Price-driven	Quantity-driven	
Regulatory	Investment focused	Investment incentives Tax credits Low interest/soft loans	Tendering system for investment grant	Environmental taxes Simplification of authorisation procedures Connexion charges, balancing costs
	Generation based	(Fixed) Feed-in tariffs Fixed premium system	Tendering system for long term contracts Tradable green certificate system	
Voluntary	Investment focused	Shareholder programs Contribution programs		Voluntary agreements
	Generation based	Green tariffs		

able portfolio standards (RPS) – typically work as follows: the generators (producers), wholesalers, distribution companies, or retailers (depending who is involved in the electricity supply chain) are obliged to supply/purchase a certain percentage of electricity from RES. At the date of settlement, they have to submit the required number of certificates to demonstrate compliance. Those involved may obtain certificates in three ways:

o From their own renewable electricity generation;
o By purchasing renewable electricity and associated certificates from another generators; and/or
o By purchasing certificates without purchasing the actual power from a generator or broker, i.e. purchasing certificates that have been traded independently of the power itself.

The price of the certificates is in principle determined on a market for these certificates (e.g. NordPool). Under the assumption of perfect market conditions this system should lead to least generation costs from renewable energy sources.

5.1.3. Voluntary approaches

This type of strategy is mainly based on the willingness of consumers to pay premium rates for renewable energy e.g. due to concern for Global Warming. There are two main categories:

- Investment focused: the most important are shareholder programs, donation projects and ethical input.
- Generation based: green electricity tariffs, with and without labelling.

5.1.4. Indirect strategies

Aside from strategies which directly address the promotion of one (or more) specific renewable electricity technologies, there are other strategies which may have an indirect impact on the dissemination of renewables. The most important are:

- Eco-taxes on electricity produced with non-renewable sources;
- Taxes/permits on CO_2 emissions;

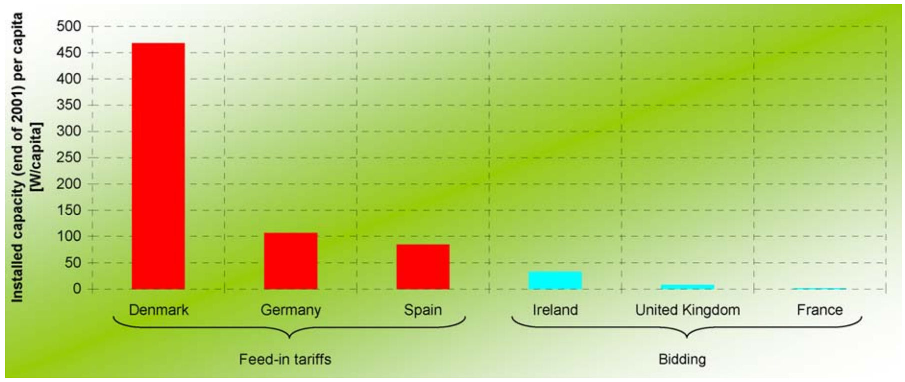


Fig. 21. Comparison of wind power deployment due to feed-in tariffs and bidding strategies for promoting wind electricity from 1990 up to 2001.
Source: Haas et al. [8].

- Removal of subsidies previously given to fossil and nuclear generation.

The promotion of renewable electricity via energy taxes or environmental taxes, two options exist:

- The exemption from taxes (energy taxes, sulphur taxes, etc.);
- If there is no exemption for RES, taxes can be (partially or wholly) refunded.

Both measures lead to an improved competitiveness for RES in the market and apply for both established (old) and new plants.

Indirect strategies also include the institutional promotion of the deployment of RES plants – planning of sitting, easy connection to the grid – and the operational conditions of feeding electricity into the system. This is particularly important in the case of intermittent production. First, sitting and planning requirements can reduce potential oppositions to RES-E plants if they address issues of concern, such as noise and visual or environmental impacts. Laws can be used e.g. to set aside specific locations for development and/or to omit areas of higher risk of environmental damage or injury to birds. Secondly, complementary measures also concern standardisation of economic and technical connection conditions. Interconnection requirements are often overly burdensome and inconsistent and can lead to high transaction costs for RES project developers; particularly if they need to hire technical and legal experts. Safety requirements are essential, in particular in the case of the interconnection in weak parts of the grid. However, unclear criteria on interconnections can potentially lead to higher prices for access to the grid and use of transmission lines; or even to unreasonable rejections of transmission access. Therefore, it is recommended that authorities clarify the safety requirements and the rules on burden of additional expenses. Thirdly, there must be rules for responsibility of physical balancing associated to intermittent production from some RES-E technologies, in particular wind power.

5.2. Historical milestones

In recent decades, electricity generation from RES has increased due to technical research, development, demonstration and technological learning. This has been due to financial support programs which have been established in many countries.

The birth of today's modern renewable energy industries can be traced largely to the pioneering activities of private Danish investors and developers in the early 1970s and to the U.S. Public Utilities Regulatory Policy Act of 1978 (PURPA), which was the earliest form of a mandatory feed-in law. The state of California developed a particularly successful tariff – called standard contract – which, when combined with available federal and state tax credits, effectively stimulated the creation of the modern new renewables industries. Having said this, because of the early state of wind power technology and because of a focus on capacity-based incentives, California's efforts did not lead to the deployment of the most reliable and efficient technologies.[7] In contrast to this, the Danish strategy of public testing and certification of wind turbines as of 1978, have, as a condition for economies, secured a high degree of technical reliability and support (Meyer [13]).

In the early 1980s financial incentives for capital expenditure, in the form of capital grants (i.e., investment subsidies), loans or reduced taxes, were the most common way of encouraging investments. The most successful examples were from Germany and Denmark, where, for instance, it was possible to obtain preferential loans for wind turbines.

In the early 1990s, in various European countries, promotional programs based on legally obligated regulated tariffs for the purchase of electricity from specified renewable sources became more common and were enhanced. The most important models in this context were fixed FIT and fixed premium systems, and the same as for all renewable generators at fixed values in Denmark, Germany, Italy and Spain. The competitive tendering system was especially tried out in the UK and France; but with very limited success. It is important to stress that the utilities were legally obliged to pay the prescribed FIT as long as the equipment was technically acceptable. Meanwhile, in the U.S., after an initial growth spurt in the 1980s, the 1990s saw relatively little new development as the FITs established in California and other states were largely abolished.

In contrast to this, the 1990s became a boom for wind power in Europe – especially in Germany, Denmark and Spain where there was a reliance on the favourable FIT scheme. More than 80% of the installed wind capacity in Europe at the end of 2000 was situated in these three countries.

However, in 2001/2002 most of these European countries decided to change the strategy due to the poor effectiveness of the tendering systems. Fig. 21 compares the dissemination effectiveness of bidding vs. FITs for wind energy in Europe before 2001, since wind energy had the far biggest share of RES-E in the nineties. The higher dissemination effectiveness of the FIT up to the year 2001 is evident. The UK in 2002 switched to a renewables obligation, Ireland and France has changed to FIT systems.

[7] Although the federal government plays an important role in providing tax incentives for renewables, states have historically been the innovators in supporting the commercial application of RES technologies in the US.

Table 2
Historical overview on promotion strategies for electricity from renewables in EU countries.

Year	Country	Type of strategy	Program name	Technologies addressed
1979–1989	DK	Investment subsidies		Wind, biogas
1989–1996	DE	Investment subsidies plus feed-in tariffs	"100/250 MW Wind Program"	Wind
1991–1993	DE	Investment subsidies plus feed-in tariffs	"1000-Dächer-Program"	PV
1990–1999	UK	Tendering system	NFFO/SRO/NI-NFFO	Selected technologies
1990–present	DE	Feed-in tariffs	"Einspeisetarif"	PV, wind, biomass, small hydro
1992–1994	AT	Investment subsidies plus feed-in tariffs	200 kW PV-Program	PV
1992–1997	IT	Feed-in tariffs	"CIP 6/92"	All technologies
1991–1996	SE	Investment subsidies/tax relief		Wind, solar, biomass
1992–1999	DK	Feed-in tariff		Wind, biomass
1992–1999	DE, CH, AT	Feed-in tariffs	"Kostendeckende Vergütung"	PV
1994–present	GR	Investment subsidies	1994-now: Operational Program for Energy and Competitiveness	PV, wind, biomass, small hydro, geothermal
1994–present	ES	Feed-in tariffs or fixed premium systems	"Royal Decree 2366/1994" resp. "Royal Decree 436/2004"	All technologies (except large hydro)
1996–present	DE, CH, NL, AT, UK	Voluntary green tariffs	Various brands	Selected technologies
1996–present	CH	Voluntary stock exchange	"Solarstrombörse"	PV
1997–present	FI	Tax incentives	Energy tax	Wind, mini hydro (<1 MW), wood based fuels
1998–present	DE	Labelled "Green Electricity"	TÜV, Grüner Stromlabel e.V., Öko-Institut	PV, wind, biomass, small hydro
1999–present	DE	Soft loans	"100,000 Dächer-Programm"	PV
1999–2000	NL	(Voluntary) green certificates		All technologies (exempt municipal waste incineration)
1979–1989	DK	Investment subsidies		Wind, biogas
1989–1996	DE	Investment subsidies plus feed-in tariffs	"100/250 MW Wind Program"	Wind
1991–1993	DE	Investment subsidies plus feed-in tariffs	"1000-Dächer-Program"	PV
1990–1999	UK	Tendering system	NFFO/SRO/NI-NFFO	Selected technologies
1990–present	DE	Feed-in tariffs	"Einspeisetarif"	PV, wind, biomass, small hydro
1992–1994	AT	Investment subsidies plus feed-in tariffs	200 kW PV-Program	PV

Source: Haas et al. [7] and own investigations.

With the ongoing liberalisation of electricity markets across Europe and other countries another type of instrument became of interest: tradable green certificates based on quota obligations for RES. In Europe this scheme has been tried in Italy, the UK and Sweden in different variations, but so far with no great success. The first application of such quota based systems occurred in the U.S., at the state level with or without TGC. Renewable energy quotas have recently become the most popular support form in the US and an increasing number of states have implemented such schemes.

In general, whilst the main goal of the support of RES was to improve the secure supply by the substitution of fossil fuels in the 1980s, the 1990s and 2000s saw environmental targets as being as equally important.

Table 2 summarises the most important historical milestones for promotional strategies.

Within this paper, the assessment of direct promotion strategies is carried out by focussing on the comparison between price-driven, (e.g. FITs) and quantity-driven (e.g. tradable green certificate (TGC)-based quotas), strategies, see Table 1. These instruments are explained in more detail below.

Feed-in tariffs (FITs) are generation-based, price-driven incentives. The price per unit of electricity that a utility or supplier or grid operator is legally obligated to pay for electricity from RES-E producers is determined by the system. Thus, a federal (or provincial) government regulates the tariff rate. It usually takes the form of either a fixed amount of money paid for RES-E production, or an additional premium on top of the electricity market price paid to RES-E producers. Besides the level of the tariff, its guaranteed duration represents an important parameter for an appraisal of the actual financial incentive. FITs allow technology-specific promotion as well as an acknowledgement of future cost-reductions by applying dynamic decreasing tariffs.

Quota obligations based on tradable green certificates (TGCs) are generation-based, quantity-driven instruments. The government defines targets for RES-E deployment and obliges a particular party of the electricity supply-chain (e.g. generator, wholesaler, and consumer) with their fulfilment. Once defined, a parallel market for renewable energy certificates is established and their price is set following demand and supply conditions (forced by the obligation). Hence, for RES-E producers, financial support may arise from selling certificates in addition to the revenues from selling electricity on the power market. With respect to technology-specific promotion in TGC systems this is also possible in principle. Yet it should be noted that a market separation for different technologies will lead to much smaller and less liquid markets. One solution could be to weight certificates from different technologies (e.g. biomass-cofiring = 1. wind = 2, PV = 8). However, the core

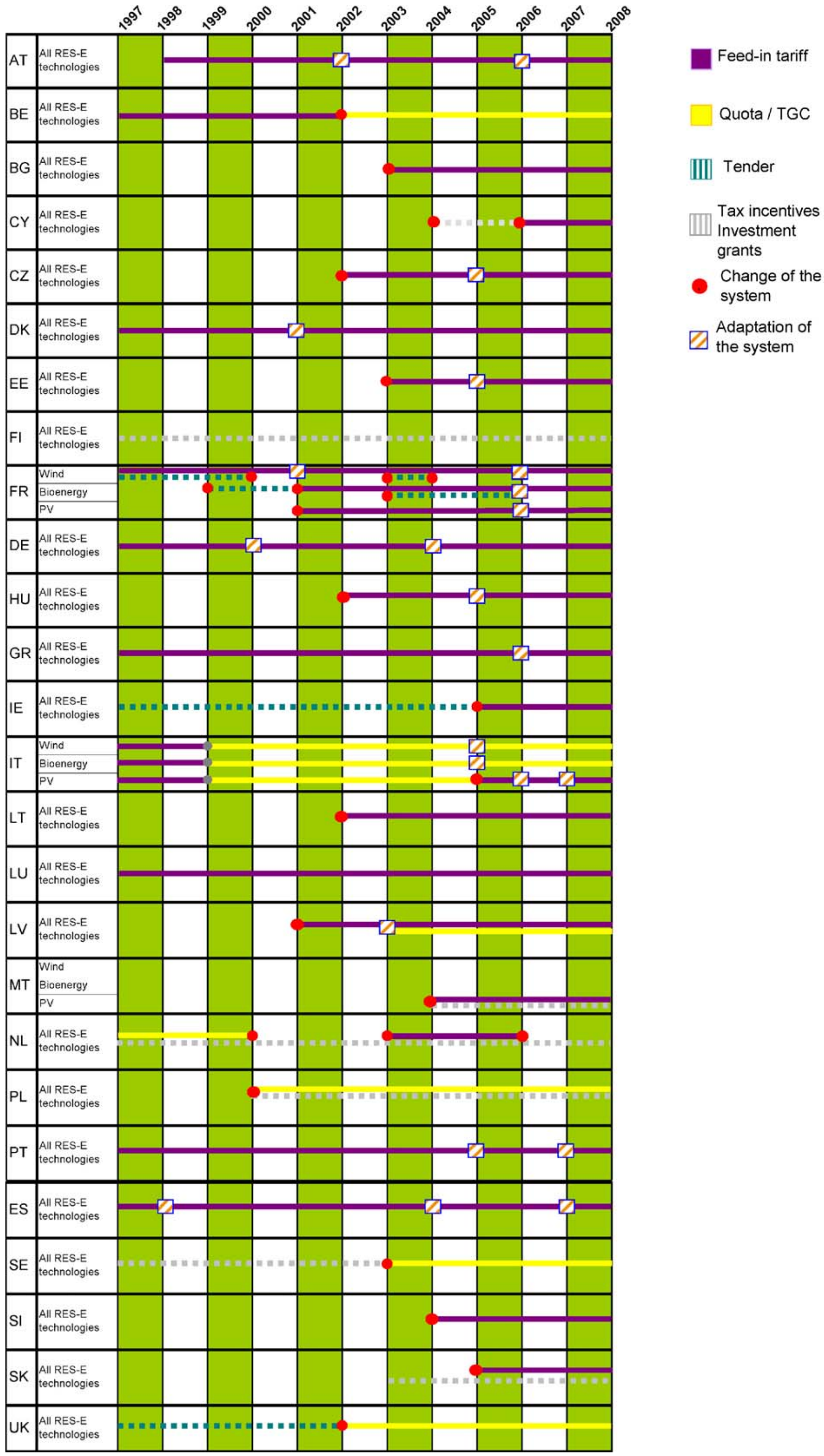


Fig. 22. Evolution of the main policy support scheme in EU-27 Member States (Ragwitz et al., 2007) [16].

dilemma is of course to find the correct or at least widely accepted weights.[8]

Tendering systems are quantity-driven mechanisms. The financial support can either be investment-focussed or generation-based. In the first case, a fixed amount of capacity to be installed is announced and contracts are given following a predefined bidding process which offers winners a set of favourable investment

[8] And of course these weights have to be adapted over time.

conditions, including investment grants per installed kW. The generation-based tendering systems work in a similar way. However, instead of providing up-front support, they offer support in the form of a ‘bid price’ per kWh for a guaranteed duration.

Investment incentives establish an incentive for the development of RES-E projects as a percentage of total costs, or as a predefined amount of € per installed kW. The level of these incentives is usually technology-specific.

Production tax incentives are generation-based, price-driven mechanisms that work through payment exemptions from the electricity taxes applied to all producers. Hence, this type of instrument differs from premium feed-in tariffs solely in terms of the cash flow for RES-E producers: it represents a negative cost instead of additional revenue.

Fig. 22 shows the evolution of the main support instrument for each country. Only 8 out of the 15 countries did not experience a major policy shift during the period 1997–2005. The current discussion within EU Member States focuses on the comparison of two opposed systems, the FIT system and the quota regulation in combination with a TGC-market. The latter has recently replaced existing policy instruments in some European countries such as Belgium, Italy, Sweden, the UK and Poland. Although these new systems were not introduced until or even after 2002, the announced policy changes caused investment instabilities prior to this date. Other policy instruments such as tender schemes are not yet used in any European country as the dominating policy scheme. However, there are instruments like production tax incentives and investment incentives, which are frequently used as supplementary instruments. Only Finland and Malta apply them as their main support scheme.

In this paper the different promotion schemes are examined with respect to the status quo. This is especially important for the “technology-specific promotion with FITs” vs. “all in one basket-promotion with TGCs”. Of course, it might improve TGC-schemes if a technology-specific component were introduced.[9] But because this approach is not currently applied in any country (with the exception of photovoltaic promotion in Italy and Belgium), we are not considering it in this analysis.

In Table 3, an overview is provided on current (i.e. as implemented at the end of 2006) promotion schemes for the support of electricity from RES in the countries investigated – listing countries, strategies and the technologies addressed. In Europe FITs serve as the main policy instrument. Finland exclusively uses tax reductions and investment incentives for the promotion of RES.

6. Review of strategies on the country level

This section summarises the major national programmes which have been implemented in practice within the different categories of promotion schemes.

The specific issues addressed are:

- description of support system (tariff or quota design) and policy targets and changes over time;
- attractiveness from investors point-of-view;
- quantities installed and level of support;
- pro’s and con’s: success aspects, problems, and future perspectives.

[9] The authors of this paper do not share this opinion.

6.1. Feed-in tariffs and premiums

In Europe FIT began to attract attention in the late 1980s especially in Denmark, Germany, Italy, and, in the 1990s, Spain. Nowadays it is the most widely used promotion instrument in Europe. As an example, Fig. 23 gives an overview on the economic level of FITs for electricity from onshore wind between 2003 and 2005.[10] It can be seen at a glance that the range is rather broad. In 2005 it varied between about 60 and 90 EUR/MWh which is mainly due to differences in wind conditions in different countries.

The FITs attract much capacity, since a fixed tariff is guaranteed, but only if the FIT is set at a level sufficient to meet investor needs (e.g. as shown by the substantial growth of wind power in Denmark in the 1990s, and Germany and Spain in the recent past; see Section 5). That is to say, sufficiently generous FITs – set above the generation cost level – are quite effective in attracting investment for renewables.

6.1.1. Case study Denmark

In terms of large scale integration of wind power in the electricity system, Denmark is in a class of its own. In 2005, nearly 20% of the country’s electricity consumption was produced with wind power,[11] see Fig. 24. The west Denmark electricity grid (which is not connected to the grid in East Denmark) covers some 24% of electricity consumption with wind power (www.ens.dk).

The major reason for this development is that wind power was given an important role in the official Danish energy plans from 1990 to 1995. The target for wind in 2005 was an installed capacity of 1500 MW covering around 10% of Danish electricity demand. This target was exceeded by a factor of two already in 2003, where the installed wind capacity had passed 3000 MW (Meyer [13]).

The main key to the Danish success in the development of wind power during the 1990s has been a stable legal framework and a favourable feed-in support scheme supported by general energy policies and long-term strategies agreed by majorities in changing Parliaments. This created a stable investment climate in the 1990s and ensured that the overall energy policy did not change dramatically until a shift to a liberal-conservative government in 2001. Another important strategic point was the Danish introduction of wind atlases for detailed evaluations of the local potential of wind energy.

With respect to the investor and ownership structure up to the early 1990s the majority of RES-E generators were cooperatives (with tax exemption for shareholders, guaranteed minimum price system and preferential treatment for the neighborhood). A new development started in the early 1990s when the Danish municipalities were forced to indicate sites suited for wind power plants. At that time many farmers saw an advantage in owning their own turbines as a financial investment that could be written off on the business account of the farm. This possibility was not available for the cooperatives. As a result many new turbines in the late 1990s were owned by farmers and developers. Since 2001, anyone, including investors from abroad, may own wind turbines in Denmark.

A broad political agreement was reached by the Danish Parliament in 2004 to increase wind power capacity over the coming years by some 350 MW through a repowering scheme. Furthermore, two tenders for offshore wind farms of 200 MW each was also part of the agreement, together with a decision to introduce full legal and ownership unbundling by separating transmission and production of electricity.

[10] The authors of this paper do not share this opinion.
[11] Adjusted to an average wind year.

Table 3
Overview of the main policies for renewable electricity in Europe EU-27.

Country	Main electricity support schemes	Comments
Austria	Feed-in tariffs combined with regional investment incentives	Until December 2004 feed-in tariffs were guaranteed for 13 years. In November 2005 it was announced that from 2006 onwards full feed-in tariffs would be available for 10 years, with 75% available in year 11 and 50% in year 12. New feed-in tariff levels are announced annually and support is granted on a first-come, first-served basis. From May 2006 there has been a smaller government budget for RES-E support. At present a new amendment is verified, suggesting to extend the duration of feed-in tariffs fuel-independent technologies to 13 years (now 10 years) and fuel-dependent technologies to 15 years (now 10 years).
Belgium	Quota obligation system/TGC combined with minimum prices for electricity from RES	Federal government has set minimum prices for electricity from RES. Flanders and Wallonia have introduced a quota obligation system (based on TGCs) with the obligation on electricity suppliers. In all three of the regions, a separate market for green certificates has been created. Wind offshore is supported at the federal level.
Bulgaria	Mandatory purchase of renewable electricity by electricity suppliers for minimum prices (essentially feed-in tariffs) plus tax incentives	Relatively low level of incentive makes penetration of renewables especially difficult as the current commodity prices for electricity are still relatively low. A green certificate system to support renewable electricity developments has been proposed to replace the mandatory purchase price for implementation in 2012. Bulgaria recently agreed upon an indicative target for renewable electricity with the European Commission, which is expected to provide a good incentive for further promotion of renewable support schemes.
Cyprus	Feed-in tariffs (since 2006), supported by investment grant scheme for promotion of RES	Enhanced Grant Scheme introduced in January 2006 to provide financial incentives for all renewable energy in the form of government grants worth 30–55% of investment. Feed-in tariffs with long-term contracts (15 years) also introduced in 2006.
Czech Republic	Feed-in tariffs (since 2002), supported by investment grants	Relatively high feed-in tariffs with lifetime guaranteed duration of support. Producer can choose fixed feed-in tariff or premium tariff (green bonus). For biomass cogeneration only green bonus applies. Feed-in tariff levels are announced annually but are at least increased by two percent annually.
Denmark	Premium feed-in tariff for onshore wind, tender scheme for offshore wind, and fixed feed-in tariffs for others	Duration of support varies from 10 to 20 years depending on the technology and scheme applied. The tariff level is generally rather low compared to the formerly high feed-in tariffs. Recently the support scheme got revised and RES generators receive again a higher premium on top of the market price. A net metering approach is taken for photovoltaics.
Estonia	Feed-in tariff system	Feed-in tariffs paid for 7–12 years, but not beyond 2015. Single feed-in tariff level for all RES-E technologies. Relatively low feed-in tariffs make new renewable investments very difficult.
Finland	Energy tax exemption combined with investment incentives	Tax refund and investment incentives of up to 40% for wind, and up to 30% for electricity generation from other RES.
France	Feed-in tariffs plus tenders for large projects	For power plants <12 MW feed-in tariffs are guaranteed for 15 or 20 years (wind offshore, hydro and PV). From July 2005 feed-in tariff for wind is reserved for new installations within special wind energy development zones. For power plants >12 MW (except wind) a tendering scheme is in place.
Germany	Feed-in tariffs	Feed-in tariffs are guaranteed for 20 years (Renewable Energy Act). Furthermore soft loans are available.
Greece	Feed-in tariffs combined with investment incentives	Feed-in tariffs are guaranteed for 12 years with the possibility of extension up to 20 years. Investment incentives up to 40%.
Hungary	Feed-in tariff (since January 2003, amended 2005) combined with purchase obligation and grants	Fixed feed-in tariffs recently increased and differentiated by RES-E technology. No time limit for support defined by law, so in theory guaranteed for the lifetime of the installation. Plans to develop TGC system; at that time the FIT system will cease to exist.
Ireland	Feed-in tariff scheme replaced tendering scheme in 2006	New premium feed-in tariffs for biomass, hydropower and wind started 2006. Tariffs guaranteed to supplier for up to 15 years. Purchase price of electricity from the generator is negotiated between generators and suppliers. However support may not extend beyond 2024, so guaranteed premium FIT payments should start no later than 2009.
Italy	Quota obligation system with TGC	Obligation (based on TGCs) on electricity producers and importers. Certificates are issued for RES-E capacity during the first 12 years of operation, except biomass which receives certificates for 100% of electricity production for first 8 years and 60% for next 4 years.
	Fixed feed-in tariff for PV	Separate fixed feed-in tariff for PV, differentiated by size and building integrated. Guaranteed for 20 years. Increases annually in line with retail price index.
Latvia	Main policy under development.	Frequent policy changes and short duration of guaranteed feed-in tariffs result in high investment uncertainty. Main policy currently under development.
	Quota obligation system (since 2002) no TGCs, combined with feed-in tariffs (phased out 2003)	Quota system (without TGC) typically defines small RES-E amounts to be installed. High feed-in tariff scheme for wind and small hydropower plants (less than 2 MW) was phased out from January 2003. Nowadays a favourable FIT system is installed for small-scale RES generators, whereas for mid-scale generators a tendering scheme is installed for most technologies.
Lithuania	Feed-in tariffs combined with purchase obligation.	Relatively high fixed feed-in tariffs for hydro (<10 MW), wind, biomass, guaranteed for 10 years. Closure of Ignalina nuclear plant which currently supplies majority of electricity in Lithuania will strongly affect electricity prices and thus the competitive position of renewables as well as renewable support. Good conditions for grid connections. Investment programmes limited to companies registered in Lithuania. Plans exist to introduce a TGC system after 2010.
Luxembourg	Feed-in tariffs	Feed-in tariffs guaranteed for 10 years (20 years for PV). Also investment incentives available.
Malta	Low VAT rate and very low feed-in tariff for solar	Very little attention to RES support so far. Very low feed-in tariff for PV is a transitional measure.
Netherlands	Feed-in tariffs (tariff zero from August 2006)	Premium feed-in tariffs guaranteed for 10 years were in place from July 2003. For each MWh RES-E generated, producers receive a green certificate from the issuing body (CERTIQ). Certificate is then delivered to feed-in tariff administrator (ENERQ) to redeem tariff. Government put all premium RES-E support at zero for new installations from August 2006 as believed target could be met with existing applicants. Premium for biogas (<2 MWe) immediately reinstated. In beginning of 2008 the government put the new support scheme, a favourable FIT system in force.

Table 3
Continued.

Country	Main electricity support schemes	Comments
Poland	Quota obligation system. TGCs introduced from end 2005 plus renewables are exempted from the (small) excise tax	Obligation on electricity suppliers with targets specified from 2005 to 2010. Penalties for non-compliance were defined in 2004, but were not sufficiently enforced until end of 2005. The RES electricity producer is entitled to sell it to the grid at least at the average market price from a previous year (published by the regulatory authority). The price was about 38 €/MWh in 2007. The fulfilment of the national targets can be done either by submitting a relevant quantity of TGC's for redemption or by paying a substitution fee (about 74 €/MWh in 2008).
Portugal	Feed-in tariffs combined with investment incentives	Fixed feed-in tariffs guaranteed for 15 years. Level dependent on time of electricity generation (peak/off peak), RES-E technology, resource, and corrected monthly for inflation. Investment incentives up to 40%.
Romania	Quota obligation with TGCs, subsidy fund (since 2004)	Obligation on electricity suppliers with targets specified from 2005 to 2010. Minimum and maximum certificate prices are defined annually by Romanian Energy Regulatory Authority. Non-compliant suppliers pay maximum price. Romania recently introduced a new legislation, promoting RES-E generation. A technology banding system provides a technology specific promotion of RES-E, whereas wind energy is eligible for 2 TGC until 2014 and biomass, biogas, biowaste and geothermal energy is eligible for even 3 TGC until 2030. PV receives 4 TGC until 2030.
Slovak Republic	Programme supporting RES and energy efficiency, including feed-in tariffs and tax incentives	Fixed feed-in tariff for RES-E was introduced in 2005. Prices set so that a rate of return on the investment is 12 years when drawing a commercial loan. Low support, lack of funding and lack of longer-term certainty in the past have made investors very reluctant.
Slovenia	Feed-in tariffs, CO_2 taxation and public funds for environmental investments	Renewable electricity producers choose between fixed feed-in tariff and premium feed-in tariff. Tariff levels defined annually by Slovenian Government (but have been unchanged since 2004). Tariff guaranteed for 5 years, then reduced by 5%. After 10 years reduced by 10% (compared to original level). Relatively stable tariffs combined with long-term guaranteed contracts makes system quite attractive to investors.
Spain	Feed-in tariffs	Electricity producers can choose a fixed feed-in tariff or a premium on top of the conventional electricity price. No time limit, but fixed tariffs are reduced after either 15, 20 or 25 years depending on technology. System very transparent. Soft loans, tax incentives and regional investment incentives are available.
Sweden	Quota obligation system with TGCs	Obligation (based on TGCs) on electricity consumers. Obligation level defined to 2010. Non-compliance leads to a penalty, which is fixed at 150% of the average certificate price in a year. Investment incentive and a small environmental bonus available for wind energy.
UK	Quota obligation system with TGCs	Obligation (based on TGCs) on electricity suppliers. Obligation target increases to 2015 and guaranteed to stay at least at that level until 2027. Electricity companies which do not comply with the obligation have to pay a buy-out penalty. Buy-out fund is recycled back to suppliers in proportion to the number of TGCs they hold. UK is currently considering differentiating certificates by RES-E technology. Tax exemption for electricity generated from RES is available (Levy Exemption Certificates which give exemption from the Climate Change Levy).

The 2004 political agreement is expected to increase wind power's share of Danish power consumption from nearly 20% in 2004 to 25% in 2008. Beyond 2008 it is expected that most of the development will have to be offshore and by the replacement of older onshore turbines ("repowering").

In 2006 about 5500 wind turbines were operating in Denmark. For the future, the Danish Wind Associations has proposed to incorporate a goal of 50% wind power by 2025 in the Danish energy plans with installations of 200 MW per year. A recently published analysis from the association shows that wind power's share of Danish electricity consumption could be increased from nearly 20% (6.6 TWh) in 2004 to 50% (19 TWh), while reducing the number of wind turbines by more than two thirds, from app. 5500 to 1750 of which 1230 onshore. The turbine types onshore are assumed to be 1 MW, 1.5 MW and 3 MW machines, all commercially available today, while the offshore turbines are assumed to be 4 MW and 6 MW turbines.

6.1.2. Case study Germany

In Germany, a fixed FIT system for electricity from RES has already been in place since 1991 when the "Electricity Feed-in Act" has been established. In 2000 this act was substituted by the "Renewable Energy Act" and a target for the share of RES in electricity generation of 12.5% to be achieved by 2010 was set. The most

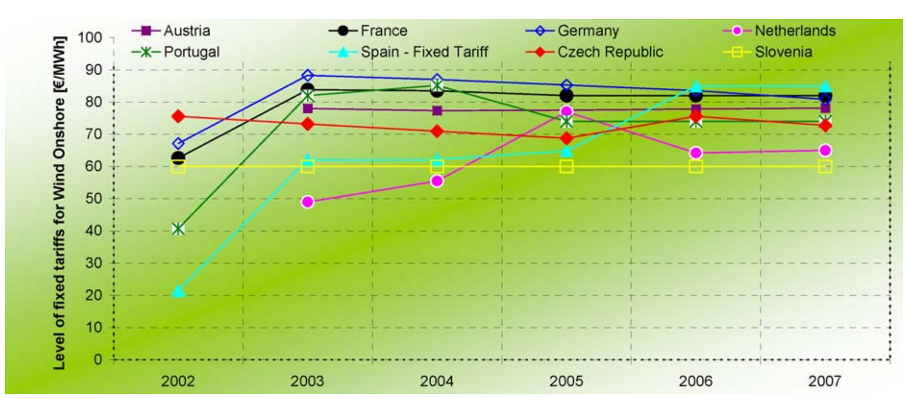


Fig. 23. Example: level of fixed FITs for electricity from wind onshore in some European countries.

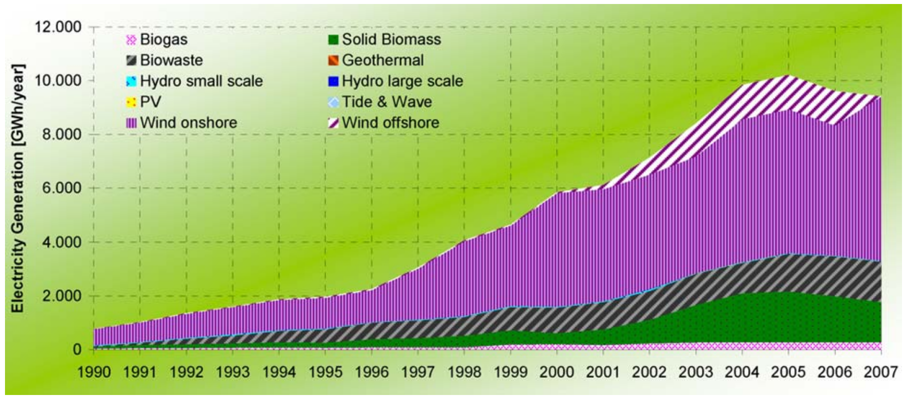


Fig. 24. Development of RES-E in Denmark from 1990 to 2007 (data based on International Energy Agency 2008, Eurostat 2008).

important change as compared to the former feed-in law was the uncoupling of the tariff level from the electricity retail price and the setting of new tariffs based on the real generation costs of a technology. Thereby, tariffs were not only differentiated on technology level, but also within a technology. The tariff was stepped according to location-specific generation costs influenced by wind speed, size of a biomass plant or the fuel type in case of biomass.

Another additional feature of the "Renewable Energy Act" is a tariff digression for new installations to encourage technology learning. The act was amended in 2004 where a 20% target for the share of renewables in electricity generation up to 2020 was fixed. In general, the FIT for wind onshore was reduced and wind power plants situated at bad wind locations were excluded from the FIT. Tariffs for geothermal electricity, small-scale biomass plants and PV increased. Furthermore additional bonuses were granted for innovative technologies and refurbishment of large hydro plants also were integrated into the feed-in support system.

Investment security for generators of green electricity is guaranteed by FITs for a time scale of up to 20 years.

Fig. 25 depicts that about two third of the total increase in electricity from RES of about 40 TWh since the early 1990s was contributed by onshore wind. Since 2000 – the year of the implementation of the "Renewable Energy Act" – more wind capacity has been connected to the grid than all previous years, leading to a total of about 11% electricity from RES in 2005 (compared to about 4% in 1997).

However, there are also some critical comments. Most of them come especially from the large incumbent utilities. They complain about a large amount of total expense for the promotion of RES. Yet, as can be seen from Fig. 23, the FIT in Germany is only slightly higher, but not overly generous, at least in terms of the price.

Another case-in-point is that most wind power plants are concentrated in the Northern part of Germany, thus putting specific local strain on the network which is also influencing load flows in other European countries. However, defenders of a stronger RES deployment argue that this is actually the task of a network.

All in all, the German way is considered a success story.

6.1.3. Case study Spain

The dominant policy instrument for the promotion of electricity from renewables in Spain is a FIT which has been in place since 1994. In 1998 two alternative payment options for green electricity generators were introduced, a fixed tariff scheme and a premium tariff, which was paid on top of the electricity market price. The choice is valid for one year, after which the generator may decide to maintain the tariff option or change to the alternative option. Under both payment options, grid connection and purchase of the green electricity are guaranteed. In 1994, the Spanish government also determined a national indicative target of 12% share of renewables in total energy consumption by 2010.

Regarding investment security in 2004, the promotion scheme was revised by ensuring the payment of feed-in tariffs during the whole lifetime of a plant. In addition, it was intended to enable a stronger market integration of renewable energies by converting the former premium option into a free market sale without purchase obligation, but, with an additional incentive for participation in the market. According to the market option, green electricity can either be sold at the market by using a bidding system or through bilateral contracts. By the end of 2004, the overall remuneration level under the market option increased more than expected due to rising electricity market prices (average electricity price in 2004 amounted to 36 EUR/MWh and in 2005 to 65 EUR/MWh).

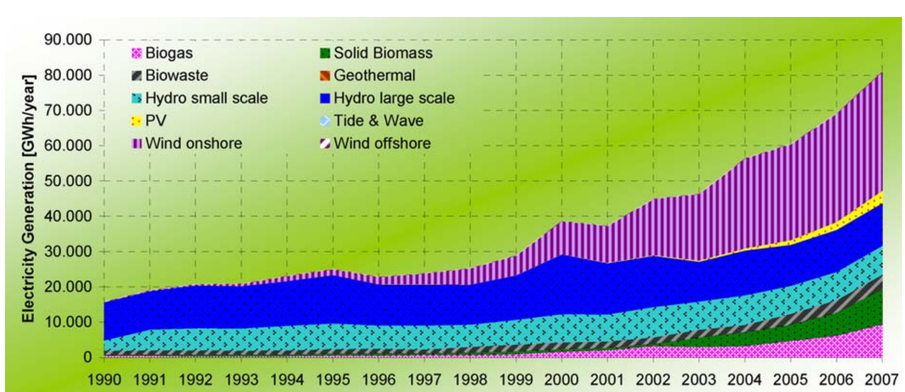


Fig. 25. Development of RES-E in Germany from 1990 to 2007 (data based on International Energy Agency 2008, Eurostat 2008).

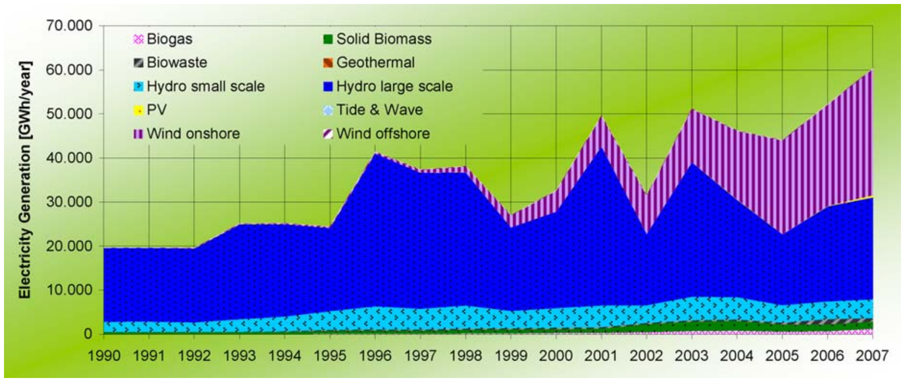


Fig. 26. Development of electricity using renewable energy sources in Spain from 1990 to 2007 (data based on Eurostat 2008).

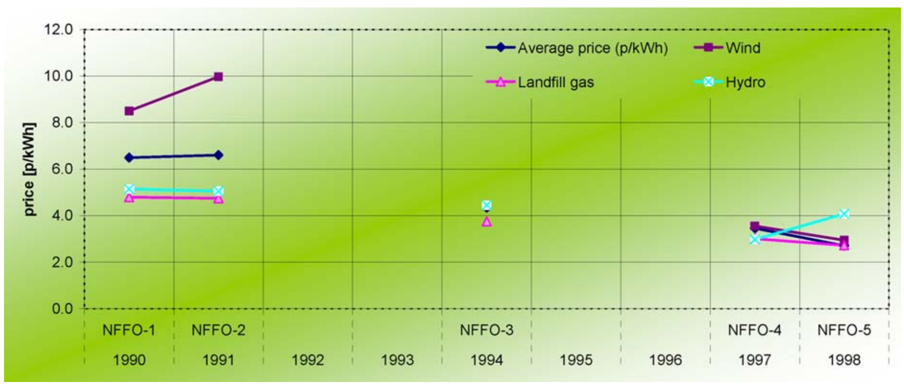


Fig. 27. England and Wales: NFFO Prices in EUR-cent/kWh.

Source: www.ofgem.uk.

As a result of these favourable support conditions, the deployment of RES in Spain started to take off in the late 1990s. Up to 2006 about 30 TWh of additional electricity from RES had been generated, where as about 80% from onshore wind, see Fig. 26

The only point-of-criticism that emerged in Spain was the high potential profit for wind generators due to the premium mentioned. Yet, by and large, the Spanish system is one of the major success stories. It has managed to bring about a significant increase in deployment at moderate support levels – see Fig. 23 – in a short period of time. Continuity and stability of the renewable energy policy even under changing governments have contributed significantly to the success of this policy instrument.

6.2. Bidding/tendering systems

Government tendering systems used to promote RES were used in the 1990s in France (for wind energy and biomass), Ireland (The Irish Alternative Energy Requirement (AER)), Denmark (the last two off-shore wind farms) and the UK, as well as in many states in the U.S. The most well-known of these promotion strategies is the Non-fossil fuel obligation (NFFO) in England and Wales, which is further described below. Similar schemes have been set up for Scotland (Scottish Renewables Order – SRO), and Northern Ireland (NI-NFFO).

However, in 2001/2002 most of these European countries decided to change the strategy due to the poor effectiveness of the tendering systems. Fig. 21 compares the dissemination effectiveness of bidding vs. FITs for wind energy in Europe before 2001. The higher dissemination effectiveness of the FIT up to the year 2001 is evident. The UK in 2002 switched to a renewables obligation, Ireland and France has changed to FIT systems.

6.2.1. Case study UK's NFFO

The original objective of the NFFO was to achieve an installed capacity from RES of 1500 MWe by the year 2000, see Connor [2]. The principle of the tendering-system was to invite developers to tender to construct a certain amount of renewable energy capacity. If the proposals were considered viable and competed successfully on price terms with other tenders within the same technology band, they were awarded a contract. The contracts, so as to facilitate bank finance, were for a relatively long period of time (up to 15 years). For those schemes contracted, a guaranteed surcharge per unit of output was guaranteed for the whole contract period. The difference between the surcharge paid to NFFO generators (premium price) and a "reference price" (Pool Selling Price) was financed by a levy on all electricity sales of licensed electricity suppliers. The costs of this levy[12] were passed on to consumers (Mitchell et al. [15]).

In total five tendering rounds were conducted in England and Wales resulting in 880 contracts being awarded. Due to competition on the supply side (bids), prices declined significantly and rapidly over time. Since the first order in 1990, average prices paid to projects awarded contracts have decreased from 6.5 p/kWh to 2.71 p/kWh in England and Wales. Fig. 27 shows the fall of contracted prices at each successive order. Even lower prices, less than 2 p/kWh, were obtained in Scotland for wind power being cheaper than electricity from coal, oil, nuclear and some natural gas.

With respect to investors view, the system provides revenue security once the contract is awarded (and as long as the plant operates).

[12] The levy remains now only to continue the previously contracted arrangements.

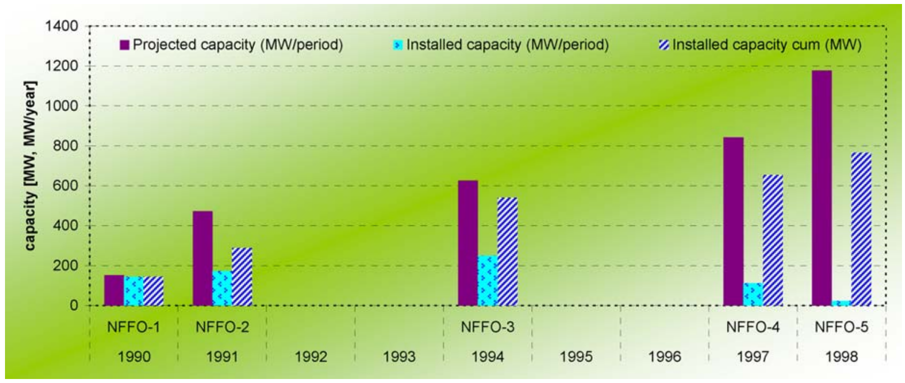


Fig. 28. England and Wales: NFFO Capacities projected and installed.

Source: www.ofgem.uk.

However, from all projects that were awarded with contracts so far, have been implemented yet. Fig. 28 shows the failure to meet the expected capacity targets. Reasons include the submission of unrealistic bid prices to secure a contract and failure to obtain planning and other consents. Similar experiences with contract failure have been commonly experienced in other bidding/tendering systems. Therefore, in some respects, tendering systems without penalties for not implementing the bid are deficient as compared with other promotion strategies. In 2002 the NFFO was replaced by the RO. Yet, approved contracts of the previous scheme continue to be valid.

It can be concluded that bidding systems may lead to low support levels but only for limited capacities at the 'best' locations.

6.3. Quota-based trading systems

Quota-based systems are now in place in six EU countries, in the U.S. as RPS in about 20 states (and the District of Columbia) and also in Japan. Table 4 summarises the most important features of the trading systems in EU countries. Fig. 29 gives a comparative overview on the prices of TGC in the last years. The most important perception is that with the exception of UK no recognizable decrease took place.

In the following the most important features of these systems are described in detail.

Case studies from Europe

Currently, quota-based TGC systems for the promotion of RES are in force in the UK, Sweden, Italy, Belgium, Poland and Romania.

In the UK, Belgium, Poland and Romania suppliers have to demonstrate the compliance with the obligation, in Sweden it has been the end-users until end of 2006 but since 2007 also the suppliers are responsible for it and only in Italy the quota has to be fulfilled by the producers (in a rather complicated way, see below). In all countries there are the following three possibilities for meeting the obligations:

- to produce certificates by generating electricity from qualifying renewable plants;
- to purchase TGCs from other eligible generators, other suppliers or traders, or exchanges;
- to pay the penalty or "Buy-Out Price" set by the regulatory authority.

6.3.1. Case study United Kingdom

Traditionally, RES-E production from large and small-scale hydro power had the biggest share from around 90% in 1990 but it strongly decreased to 34% in 2006. Nowadays the most important source of renewable electricity was generated from biogas, amounting to 35% of the total RES-E production in 2006. Responsible for its increase was the production of electricity from landfill gas, which currently accounts for more than 90% of the biogas. Solid biomass is currently showing the strongest annual growth rates and contributes around 20% to the total RES-E generation. Electricity generated by wind onshore is constantly increasing very strong as well. Moreover, since 2004 several offshore wind farms are installed and grid-connected too. Fig. 30 illustrates the above mentioned deployment of RES-E generation in the United Kingdom between 1990 and 2006.

In the UK the Renewables Obligation (RO) came into force in 2002. It started with 3.4% coverage of electricity demand for the period of 2003/2004 and will increase to 10.4% in 2010/2011 and – afterwards – remain on a constant level until 2027.

The major problems of the RO are that certificate prices are high (although slightly decreasing from 2003 to 2005 but increasing again since then – see Fig. 29) and that so far the quota has never been fulfilled. E.g., in 2004 only 2.2% of electricity has been generated from "new" RES while the quota was 3.4%.

Notice that, because of multi-risk for the producers, developers and for obligated suppliers, most of the quotas are complied within long term contracts between suppliers and producers – or more importantly within vertical integration – and the exchange of certificates does not play the role that the theory could suggest.

In fact, not meeting the target is also a function of at least[13] three major factors: (i) the low penalty, respectively the fact that this penalty is recycled to the renewable generators (see above); (ii) location and permitting constraints; and (iii) banking is not allowed so RES generators fear (with good reasons) that the closer they come to the quota the lower will be the ROC price. Note that this is despite the fact that long term contracts are possible and most of the certificate handling takes place within vertically integrated large companies.

The penalty mechanism in the UK deserves special attention. All penalty payments are placed in a central fund. This fund is redistributed to suppliers which have met the obligation in proportion to the number of ROCs each supplier has presented. Therefore the real costs for a supplier who is not complying with the obligation are higher than their total Buy-Out Price payments ('fines'). In contrast, accomplishing and surpassing the RO target provides additional economic incentives. That explains why ROC prices were higher than the Buy-Out price in the first years. This situation can be expected as long as the market is short of electricity from RES.

[13] Of course, more investigations are necessary to get detailed insight on the effects of a hybrid instrument (control by quantity – the quota – and by price – the buy out price) to explain its poor environmental effectiveness.

Table 4
Quota-based TGC systems in EU countries.

MS	Quota target	Involved technologies	Obliged stake-holder	Penalty €/MWh	Minimum limit €/MWh	Technology-specific quota	Existing plants eligible
BE Flanders	1.2% in 2003 6% in 2010	All RES, no MSW	Supplier	75 in 2003; 100 in 2004; 125 in 2005	65	No	Yes
BE Walloon	3% in 2003 12% in 2010	All RES and high quality CHP	Supplier	100	Hydro: 95; solar: 450; wind, biomass and others: 80	No	Yes
IT	2% in 2002 and increased annually by 0.35% between 2004 and 2008	All RES (incl. large hydro, MSW, hydrogen and CHP)	Producers and importers	No penalty is set; the grid operator sells certificates at a fixed price: 12,528 (2006)	No	Shortened certificate validity for biomass electricity	No (for certificate trade), Yes (for quota fulfilment)
PL	7.5% in 2010	Small and large hydro, wind, biomass	Supplier	100	No	No	No
RO	0.7% in 2005 4.3% in 2010	Wind, solar, biomass and hydro <10 MW	Supplier	45.3 in 2005	30.2 in 2005	No	Yes, except hydro: only new or rehabilitated plants since 2004
SE	7.4% in 2003, 16.9% in 2010	Small hydro (<1.5 MW), large hydro (only some cases), wind, biomass, geothermal, wave	End-user until 2006, supplier from 2007 on	150% of the market price	Transitional floor prices): 2003: 6.6; 2004: 5.5; 2005: 4.4; 2006: 3.3; 2007: 2.2; 2008: 0	No	Yes (small hydro)
UK	3% in 2003, 10.4% in 2010	Small hydro, wind, biomass, solar-, geo-thermal energy, no MSW	Supplier	30 in 2002/2003, 30.5 in 2003/2004, 31.4 in 2004/2005	No	Introduction of technology banding is planned for the future	No

Source: Ragwitz et al., 2007 [16], METI (2007).

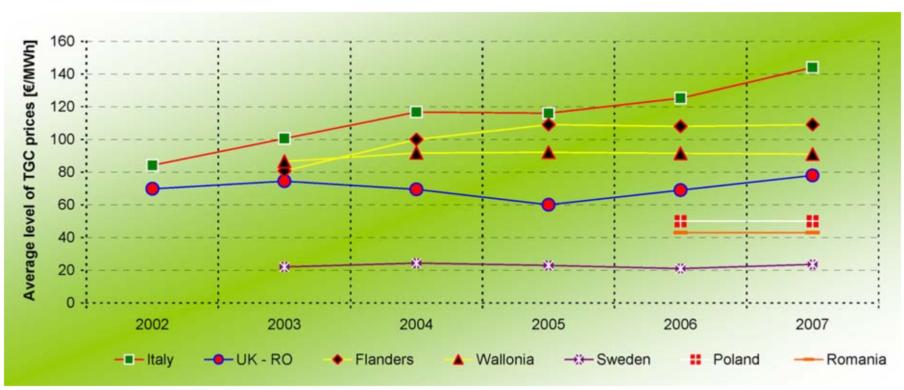


Fig. 29. Comparison of premium support level: value of TGCs.

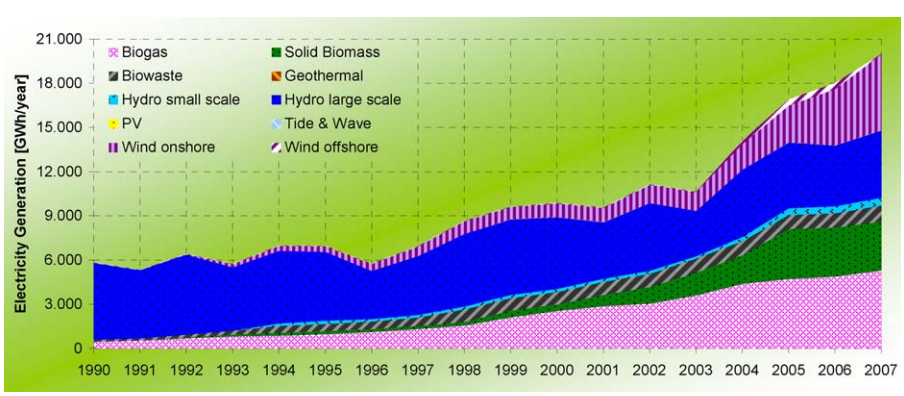


Fig. 30. Development of electricity from renewable energy sources in the UK in 1990 to 2007 (data based on Eurostat 2008).

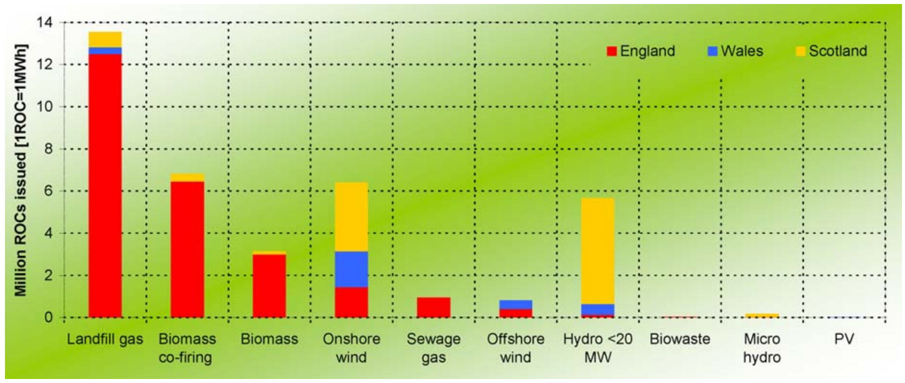


Fig. 31. Number of million ROCs issued in the period April 2002 to March 2006 by technology and country (*Note*: 1 ROC = 1 MWhel).
Source: OFGEM (2007).

Fig. 31 depicts the number of ROCs issued in UK between October 2002 and March 2005 by technology and country.[14] Clearly, in England the cheap options landfill gas and biomass co-firing dominate. In Wales and Scotland onshore wind and hydro are also among the preferred options.

6.3.2. *Case study Italy*

Fig. 32 depicts the contribution of the different technologies of RES-E generation in Italy. Hydropower represents around 80% of the RES-E generation in 2006, including both large-scale and small-scale plants. With a total share of the RES-E generation, amounting to about 10%, the second most important electricity generation methodology is geothermal. Onshore wind installations show a strong increase in the last few years and moreover photovoltaics grew by nearly 700% in the period 1990–2003.

In Italy, in 2002 a TGC system started. An obligation was put on all the producers and importers of electricity to supply 2% of their power from new renewable electricity, with exceptions for combined heat and power plants, renewables and companies generating less that 100 GWh.

Today the situation in Italy is similar to the British case. TGC prices are the highest in Europe (see Fig. 29) mainly because of their low validity period of eight years. The role of the certificates sold by GSE is to reconcile the previous feed in programme with the new support scheme based, and is based on the market as can be seen clearly, as GSE supplied most of the TGCs in 2002, whilst steadily reducing its role as new plants came on line in the following years. As a matter of fact, the equilibrium of the market is quite delicate and the quota of the obligation has to be constantly kept under control to avoid that the supply of certificates from new plants exceeds demand. In this case the price of certificates would go, in theory, to zero. To facilitate this control and give elasticity to the supply, banking of certificates has been allowed for two years.

The increase of the reference price of the TGCs sold by GSE, is due to the mechanism for the price setting. When the generation of low price sources like hydro power is low, the weighted average of the price paid for former feed-in contracts is higher and so the price of certificates. The same happens when the avoided cost, which has a cost factor related to the fuel prices, is higher, as in 2006, with a heavy influence of the previous support mechanism on the present market.

6.3.3. *Case study Belgium*

Solid biomass has shown strong growth rates in the past and therefore it accounts to the largest contributor of RES-E generators in Belgium. Around 50% of the Belgium RES-E generation comes from solid biomass. Electricity from biowaste contributes a constant amount of electricity every year whereas the production of RES-E from biogas dropped in the year 2006. Small-scale and large-scale hydro power generation decreased slightly within the last few years but therefore electricity generated by onshore wind turbines increased strongly in the last year. Fig. 33 illustrates the above mentioned deployment of RES-E generation in the Belgium between 1990 and 2007.

In Belgium, two TGC systems have parallel been in existence in Flanders and Walloon since 2002. For Flanders, a comprehensive analysis is available, see Verbruggen [19]. This system started with the promotion especially of waste, biomass and wind. Yet, it was clear from the beginning, that due to the small market, liquidity would be a problem. Hence, also some already existing capacity was allowed to qualify for the quota. The penalty in Belgium for not fulfilling the quota – in the magnitude of 100–125 EUR/MWh cannot be considered as posing a serious threat because it is in the same range as the actual certificate prices, see Fig. 29. Currently, the TGC prices in Flanders are among the highest in Europe, see Fig. 29. If the windfall profits due to the promotion of old existing capacity (see Verbruggen [19]) are taken into account, the additional costs for customers for generating new electricity from RES increase to about 18 cent/kWh.

6.3.4. *Case study Sweden*

RES-E generation in Sweden is dominated by hydro power, primarily large-scale plants and several small-scale plants. Solid biomass showed a strong increase in the last few years with growth rates of about 200%. Generation of electricity from wind, both onshore and offshore, started to grow slightly since 2003 whereof photovoltaics are still in an early stage, see Fig. 34.

A case in point is Sweden. In 2004 and 2005 capacities of new RES installed increased significantly when certificate prices were at a low level – see Figs. 29 and 34. Yet, two additional aspects are important: (i) in the Swedish quota system some old capacity was allowed.[15] This led to some "free riding" capacities and the resulting "windfall profits" – the profits due to plants which had been constructed and paid before the TGC system was started – and hence the specific costs per kWh of new RES capacities are higher; (ii) in addition to the TGC system in these years tax incentives and investment subsidies especially for wind power plants were available. In 2007 Sweden switched the responsibility of having to demonstrate the compliance with the obligation from the end-users to the supplier's side.

[14] The UK ROCs system has not directly affected small generators, e.g. roof PV, small wind, and small hydro.

[15] Recently, this system has been modified and currently mainly new capacities qualify for certificates traded.

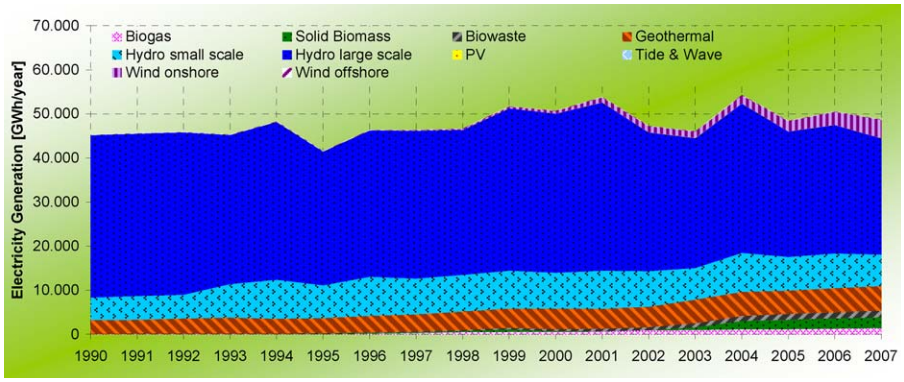


Fig. 32. Development of electricity using renewable energy sources in Italy from 1990 to 2006 (data based on Eurostat 2007).

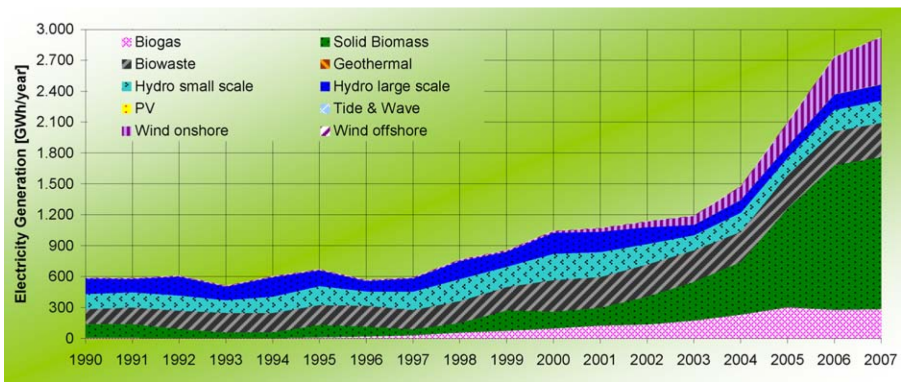


Fig. 33. Development of electricity using renewable energy sources in Belgium from 1990 to 2007 (data based on Eurostat 2008).

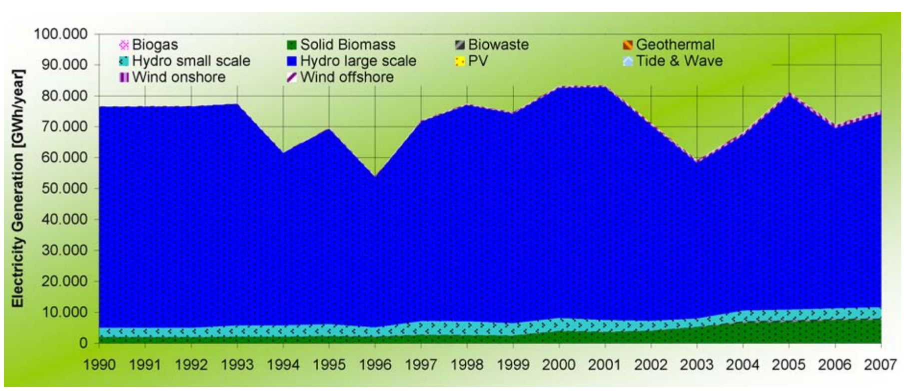


Fig. 34. Development of electricity using renewable energy sources in Sweden from 1990 to 2007 (data based on Eurostat 2008).

6.4. Investment incentives

The cumulative installed capacity in the four big current photovoltaics markets is depicted in Fig. 35.

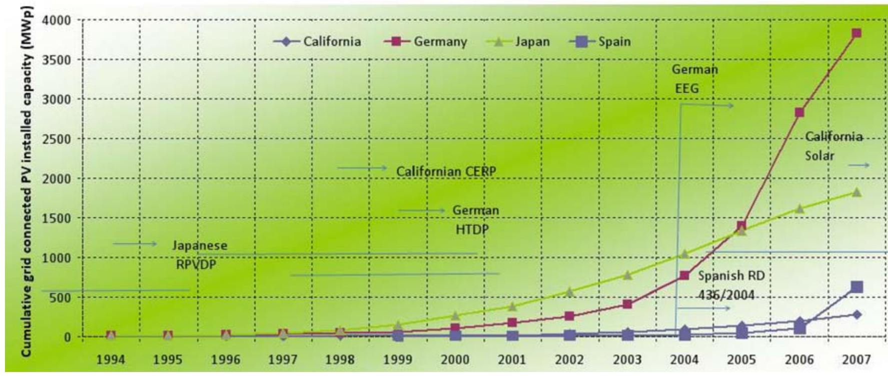
6.4.1. Case study: the German 1000 roofs and 100,000 roof-top PV programs

The first comprehensive international dissemination PV program was the “1000 roofs program” launched in Germany in 1989 and completed in 1994. Some 2250 German roofs were equipped with PV systems of an average size of 2.6 kWp and a total capacity of about 6.15 MWp. Average system costs were 15,000 USD/kWp, average subsidies 70% of the investment costs.

An expansion of the 1000 roof program, the 100,000 roofs program was launched in 1999. The objective of the program was to promote 100,000 installations with an average size of 3 kWp, i.e. 300 MWp in total. Within this program low-interest loans were provided. The development of costs, rebates and installed capacity is shown in Fig. 36. A lot of “Stop and Go” took place since the start of this program. Initially the interest rate was set at 0% at a payback time of ten years. The initial response to the program between 1999 and 2002 was rather moderate, see Fig. 36.

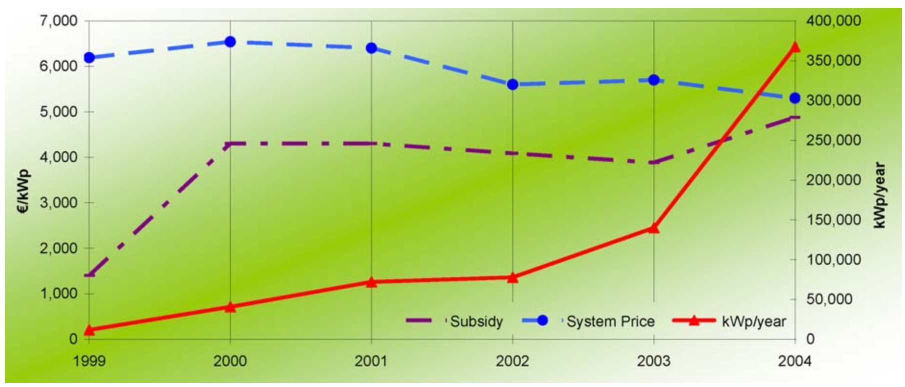
In 2000 the interest rate was raised from 0% in 1999 to 1.8% and favourable feed-in tariffs of 50.6 €Cent/kWh were introduced. The possible accumulation of these two instruments led finally to an impressive deployment of PV capacities within this program – see Fig. 36. All in all, 261 MW were supported by the 100,000 roofs program.

Regarding the success factors in this program it is not yet possible to determine which instrument had more influence on increasing the rate of installations: the cheap loan or the FIT.



Source: Lopez et al., 2009.

Fig. 35. Cumulative installed capacity with important milestones in the biggest PV markets.



Source: Lopez et al., 2007.

Fig. 36. The German 100,000 roofs programme: development of costs, rebates and installed capacity.

6.5. *Investment-based tax incentives*

Several different options have been used to promote the generation of electricity from RES with fiscal instruments:

- lower VAT-rate applied for renewable electricity systems;
- dividends from RES-investment made exempt from income taxes.

These two options have similar impact, acting as investment subsidies for new installations. Table 5 gives an overview of existing investment-based tax incentives in EU countries.

7. What works and why: effectiveness and efficiency of promotion policies

Reviewing the programmes and instruments described above the core question is whether these programmes have been successful or not. To assess the success the most important criteria are:

Effectiveness: Did the support programmes lead to a significant increase in deployment of capacities from RES-E in relation to the additional potential? The effectiveness indicator measures the relation of the new generated electricity within a certain time period compared to the corresponding potential of the technologies.

Economic efficiency: What was the absolute support level compared to the actual generation costs of RES-E generators and what was the trend in support over time? How is the net support level of RES-E generation consistent with the corresponding effectiveness indicator?

Further major performance criteria of interest are: credibility for investors and the reduction of costs over time.

This chapter provides a summary on the specific/relevant performance parameters. In the following sub-chapters these criteria are discussed in detail. Needless to say, resource endowments of RES as well as existing power systems vary depending on countries; therefore, the further considerations are needed to observe actual effects of policy instruments.

7.1. *Effectiveness of policy instruments*

First the effectiveness of policy instruments is analysed looking at the quantities installed. To make the performance between different countries comparable the figures are related to number of capita. Moreover, we look at all new RES-E in total as well as on wind and PV in detail. Effectiveness indicators of policy instruments have also been analysed by Hamerlink et al. [9].

Fig. 37 depicts the policy effectiveness for electricity generation from all “new” RES for 1998–2005 measured in the incremental amount of RES-E per year and capita. Clearly, it was highest in Denmark with about twice as high renewable electricity deployed than the next ranked countries Finland, Sweden, Spain and Germany. It should be noticed, however, that since 2003 the net increase in wind power capacity has been close to zero in Denmark. It is of interest that among these countries quite different promotion schemes exist: a quota-based TGC system in Sweden, investment incentives in Finland and FITs in the other countries. In the Nordic countries cheap electricity from biomass plays a con-

Table 5
Tax incentives in various EU countries (as of 31st December, 2006).

Country	Investment-based tax incentives
Austria	Private investors get tax credits for investments in using renewable energies (personal income tax). The amount is generally limited to 2.929 € per year
Belgium	13.5–14% of RES-investments deductible from company profits, regressive depreciation of investments. Reduced VAT on building retrofit if energy efficiency is included (6% instead 21%)
Denmark	The first 3000 DKK of income from wind energy are tax free
France	Deduction of 15% investment costs with a maximum of 3000 € per person. Reduced VAT (5.5%) on renewable equipment (not applicable to installation costs)
Germany	Losses of investments can be deducted from the taxable income. This fact increases return on investments into wind projects
Greece	Up to 75% of RES-investments can be deducted
Ireland	Corporate Tax Incentive: tax relief capped at 50% of all capital expenditure for certain RES-investments
Italy	VAT reduced to 10% for investments in wind and solar; 36% deduction of PV, solar thermal and energy efficiency investments up to 54,000 € (55% from 2007)
Portugal	Up to 30% of any type of investments on RES can be deducted with a maximum of 700 € per year. Reduced VAT (12%) on renewable equipment
Spain	Corporation tax: 10% (up to 20% in some autonomous regions) tax liability instead of 35% for investments in environment friendly fixed assets
The Netherlands	EIA scheme: RES-investors (most renewable energy systems) are eligible to reduce their taxable profit with 55% of the invested sum
	Lower interest rates from Green Funds: RES-investors (most renewable energy systems) can obtain lower interest rates (up to 1.5%) for their investments. Moreover dividends gained are free of income tax for private investors

Sources: Ragwitz et al. 2007 [16].

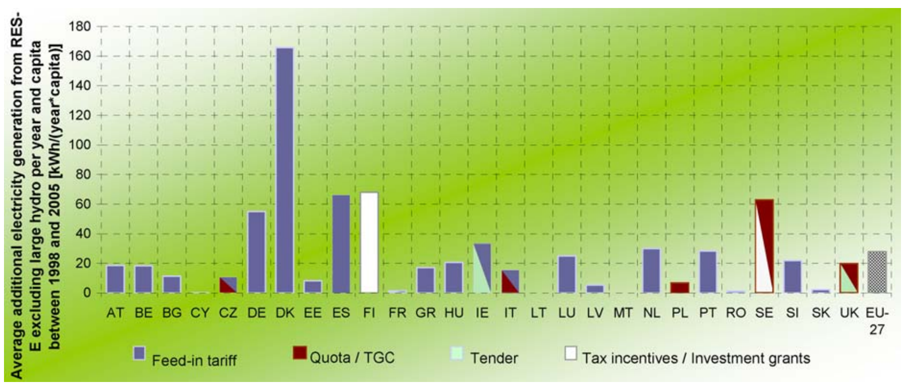


Fig. 37. Policy effectiveness of support measures for electricity from “new” RES (excl. hydro) measured in additional kWh per year and capita for the period 1998–2005 in the EU.
Sources: EUROSTAT (2006), IEA (2006b).

siderable role. Note, that progress was generally much slower in new Member States than in the old EU-15 countries. Of the former, Hungary and Latvia showed the highest relative growth in the period considered.

Fig. 37 depicts the policy effectiveness of total RES-E support for the period 1998–2005 measured in yearly additional electricity generation in comparison to the remaining additional available potential for each EU-27 Member State. The calculations refer to following principal:

$$E_n^i = \frac{G_n^i - G_{n-1}^i}{ADDPOT_n^i} = \frac{G_n^i - G_{n-1}^i}{POT_{2020}^i - G_{n-1}^i}$$

E_n^i	Effectiveness indicator for RES technology i in the year n	G_n^i	Existing electricity generation potential by RES technology i in year n
	Additional generation potential of RES technology i in year n until 2020		Total generation potential of RES technology i until 2020

It is clearly noted that countries with feed-in tariffs as support scheme achieved higher effectiveness compared to countries with a quota/TGC system or other incentives. Denmark achieved the highest effectiveness among all Member States but again it has to be mentioned that hardly any new generation plants have been installed in recent years, whereas the opposite happened in Germany and Portugal, with a strong increase in the recent past. Among the new Member States, Hungary and Poland have implemented the most efficient strategies in order to promote “new” renewable energy sources, see Fig. 38.

Since Fig. 38 depicts the effectiveness indicator for the total renewable electricity, the following figures demonstrate the effectiveness by technology.

Looking at wind onshore only – Fig. 39 – the EU countries with the highest policy effectiveness during the considered period, Demark, Germany, and Spain, applied fixed feed-in tariffs during the entire period 1998–2005 (except a system change in Denmark in 2001). The resulting high investment security as well as low administrative barriers stimulated a strong and continuous growth in wind energy during the last decade. As can be observed from a country like France, high administrative barriers can significantly hamper the development of wind energy even under a stable policy environment combined with reasonably high feed-in tariffs.

With respect to PV – still one of the most expensive RES technologies – the depicted examples of Germany and Japan had the highest policy effectiveness along with Luxemburg who’s small population is not really representative (Fig. 40). Obviously, generous FITs – as in Germany, Luxembourg, and Japan (voluntary net metering) – have played an important role to promote PVs.

7.2. Economic efficiency

Next we compare economic efficiency of the described support programs. In this context three aspects are of interest: absolute support levels, total costs to society and dynamics of the technology.

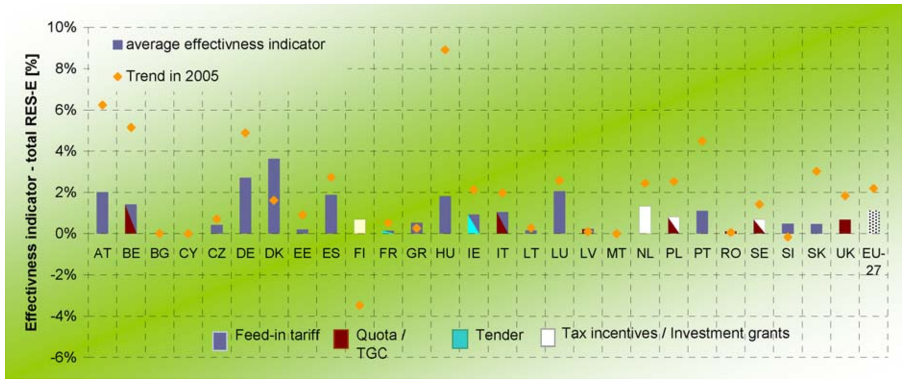


Fig. 38. Policy effectiveness of total RES-E support for the period 1998–2005 measured in yearly additional electricity generation in comparison to the remaining additional available potential for each EU-27 Member State. (Data base: EUROSTAT (2007).)

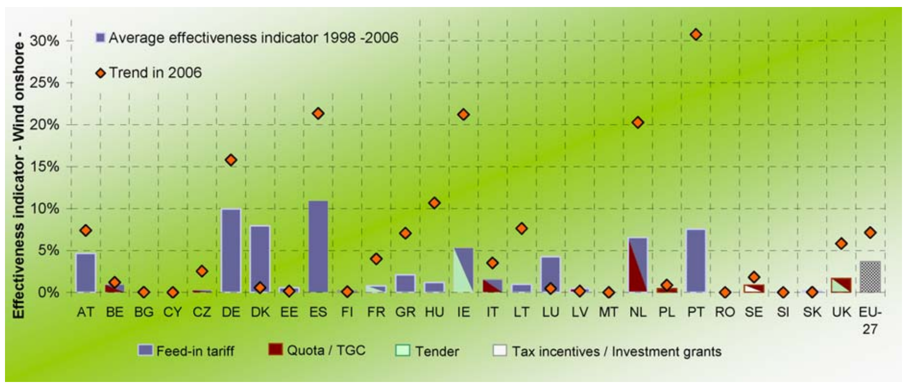


Fig. 39. Policy effectiveness of wind onshore electricity support measured in additional electricity generation per year and the additionally available potential in the period 1998–2005 in the EU-27 countries.

Source: EUROSTAT (2006).

Fig. 40. Policy effectiveness of PV electricity support measured in additional electricity generation per year and the additionally available potential in the period 1998–2005 in the EU-27 countries.

Source: EUROSTAT (2006).

As an indicator in the following the support levels are compared for wind power in the EU-27 specifically.[16]

Fig. 41 shows that, the support level and the generation costs are mostly very close. Countries with rather high average generation costs frequently show a higher support level.

A clear deviation from this rule can be found in the three quota systems in Belgium, Italy and the UK, for which the support is presently significantly higher than the generation costs. The reasons for the higher support level expressed by the current green certificate prices may differ. Main reasons are risk premiums, immature TGC markets, and too short validity times of certificates (Italy, Belgium).

For Finland, the level of support for wind onshore is too low to initiate any steady growth in capacity. In the case of Spain and Germany, the support level indicated in Fig. 41 appears to be above the average level of generation costs. However, the potentials with rather low average generation costs have already been exploited in these countries due to the recent successful market growth. Therefore a level of support that is moderately higher than average costs seems to be reasonable even if it results in windfall profits for some

[16] A comparison of all new RES would provide too broad ranges for generation costs as well as for support measures.

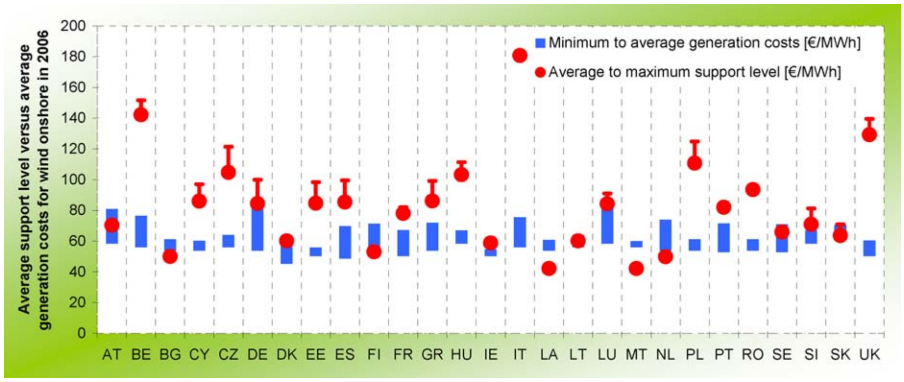


Fig. 41. Wind onshore: support level ranges (average to maximum support) in EU countries in 2006 (average tariffs are indicative) compared to the long-term marginal generation costs (minimum to average costs). Support level is normalized to 15 years.
Source: Adapted from Ragwitz et al. (2007) [16].

wind power owners. In an assessment over time also the potential technology learning effects should be taken into account in the support scheme.

More technologies, as biogas, solid biomass, small hydro power and photovoltaics are discussed in the following part below.

Electricity produced based on biogas is characterised by a large range of electricity generation costs according to biogas type, plant size and technology. In general, large centralized plants using landfill gas are more cost-effective than small-scale applications based on agricultural biogas. The financial support level for electricity produced with biogas differs significantly between the countries. Fig. 42 shows that the support level is insufficient to promote the use of biogas for electricity generation in several countries including Bulgaria, Finland, France, Latvia, Lithuania, Malta, the Netherlands and Slovenia. A support level exceeding considerably the level of generation costs is offered by countries using feed-in tariffs (Austria, Germany) as well as by countries using quota systems (Belgium, Italy and the UK). In Austria and Germany, the high tariff level targets rather the promotion of cost-intensive small-scale plants based on agricultural biogas than large centralized plants. Other countries such as Cyprus, Hungary, Luxembourg, Belgium and Romania also apply varying tariffs for electricity from biogas, mainly according to plant dimension and the type of biogas used.

Similar as in the case of biogas, electricity generation costs for the use of solid biomass show large ranges depending on fuel type, plant size and whether biomass is used in terms of cost-effective co-firing, see Fig. 43. As regarding the biomass input forestry residues, most of the EU-Member States offer financial support above electricity generation costs. In particular Estonia, Greece, Luxembourg, Romania and Slovenia set the support well adjusted to the range of electricity generation costs providing a moderate profit for cost-effective biomass plants. Since the use of biomass in large scale (co-firing) plants represents one of the most cost-effective options to generate electricity from RES, the technology-uniform support of quota systems as for instance in Belgium, Italy and the UK, might lead to windfall profits in this sector. As compared to that, the high level of feed-in tariffs in Austria, Germany and Spain aim at promoting more expensive small-scale plants.

Regarding the support of small-scale hydropower, some European countries such as Bulgaria, Cyprus, Finland, Latvia and Lithuania do not provide sufficient support in order to guarantee profitable investments, see Fig. 44. Only in Poland and the UK the support level seems to be clearly above electricity generation costs, whereas in the remaining countries, support levels are well adjusted or no considerable small-scale hydropower potential is available.[17]

As electricity generation based on solar photovoltaics represents one of the most cost-intensive options to produce RES-E, the support level is too low to stimulate investments in the majority of the EU-Member States, see Fig. 45. In countries using technology-uniform quota systems the support is insufficient, since only the most cost-effective technology options are promoted. Only Germany, France, Greece, Italy and Portugal set their tariffs close to the average generation costs. Even though Italy uses a quota obligation for most RES-E technologies, photovoltaics apply for feed-in tariffs in order to allow for profitable investments.

Fig. 46 illustrates a comparatively overview of the ranges of TGC prices and premium FITs in selected EU-27 countries. With the exception of Sweden the TGC prices are much higher than the premium received by the investors if guaranteed FITs are eligible, explaining also the high level of support in these countries as it is demonstrated in Fig. 46. Additionally, a trend towards more efficient designs in FITs in the recent past becomes obvious from Fig. 46. However, this trend has not yet been notices in quota markets based on TGCs.

7.3. Comparison of effectiveness and financial indicators

Next the relation between quantities deployed and the level of support is analysed. It is often argued that the reason for higher capacities installed is a higher support level. Although it should be noted that the resource endowments of RES vary depending on each country, as can be seen from Fig. 47 actually the opposite is true. The countries with highest support levels – Belgium and Italy – are among those with the lowest specific deployment. On the other hand, high FITs especially in Germany are often named as the main driver for investments especially in wind energy. However, the support level in Spain and Germany is not particularly high compared with other countries analysed here.

Fig. 47 above compares the effectiveness indicator, defined as new generated electricity within one year to the additional potential of RES-E, to the net support level of total RES-E technologies excluding hydro plants between 2005 and 2006. Notable are that higher efficient countries as Austria, Germany, Portugal or Spain have introduced feed-in tariffs whereas countries with less effectiveness and high support, as Italy, Belgium, UK operating a quota system.

[17] In countries where no significant small-scale hydropower potential is available, no cost ranges were shown.

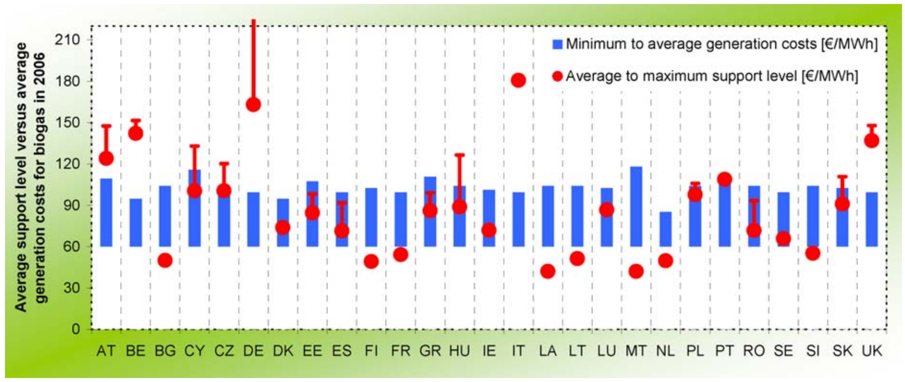


Fig. 42. Biogas: support level ranges (average to maximum support) in EU countries in 2006 (average tariffs are indicative) compared to the long-term marginal generation costs (minimum to average costs). Support level is normalized to 15 years.
Source: Adapted from Ragwitz et al. (2007) [16].

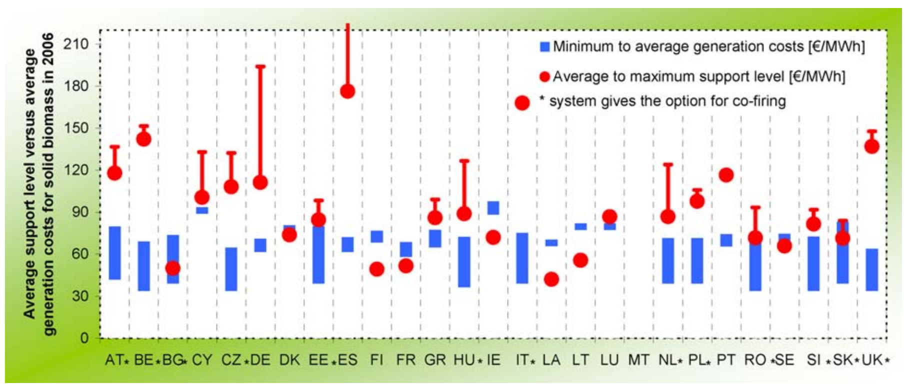


Fig. 43. Biomass forestry residues: support level ranges (average to maximum support) in EU countries in 2006 (average tariffs are indicative) compared to the long-term marginal generation costs (minimum to average costs). Support level is normalized to 15 years.
Source: Adapted from Ragwitz et al. (2007) [16].

The following additional character of TGC/quota instrument should be considered to explain the poor performance of this system in Europe. While it is supposed to be a quantity-driven instrument, which should reflect a higher likelihood of target achievement by comparison to a FIT system, in fact it is a hybrid instrument of control by quantity and price due to inclusion of a (relatively low) buy-out price. In the case where a government sets the buy-out price near the cost of the marginal project, the respect for the decided quota could be ruined. In such a case, renewable capacity development could be slowed down, stay far below the quota and thus miss the original target, as illustrated by the British experiment of the ROC system. The TGC/quota system thus needs refining in order to fulfil the targets in practice.

The effectiveness indicator defined above is shown vs. the annuity expected in each country for an investment in wind energy realised in 2006 In this way it is possible to correlate the effectiveness of a policy with the levelised profit and to analyse whether the success of a specific policy is primarily based on the high financial incentives, or whether other aspects have a crucial impact on the market diffusion of wind power in the countries considered.

One possible way to calculate the actual support over the entire lifetime from an investor's perspective is to determine the aver-

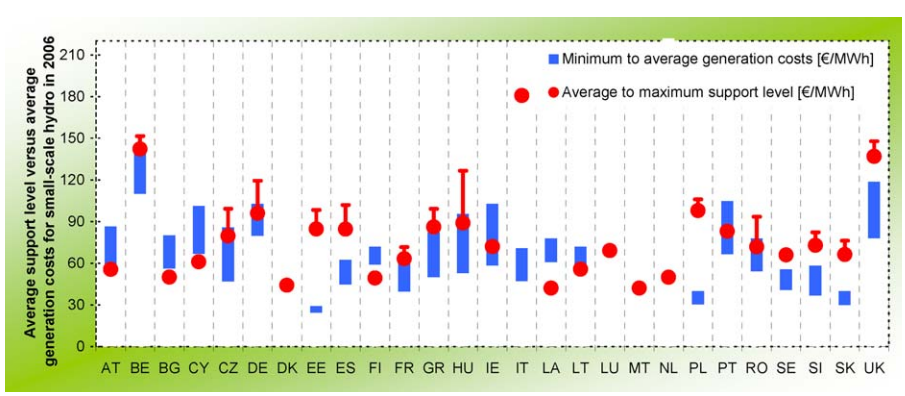


Fig. 44. Small-scale hydro power: support level ranges (average to maximum support) in EU countries in 2006 (average tariffs are indicative) compared to the long-term marginal generation costs (minimum to average costs). Support level is normalized to 15 years.
Source: Adapted from Ragwitz et al. (2007) [16].

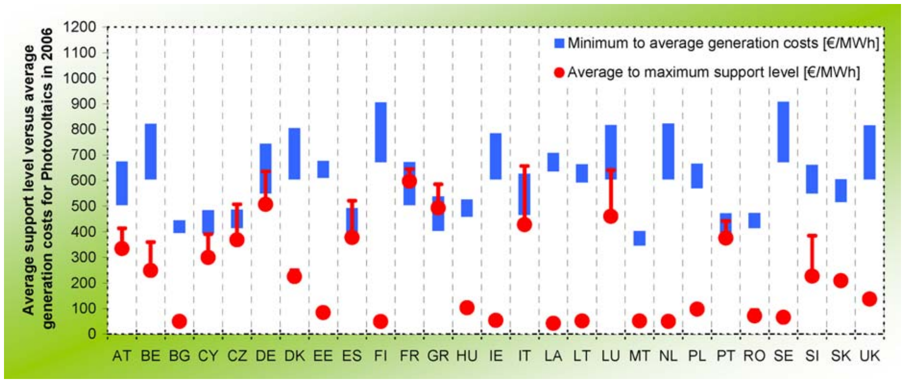


Fig. 45. Solar photovoltaics: support level ranges (average to maximum support) in EU countries in 2006 (average tariffs are indicative) compared to the long-term marginal generation costs (minimum to average costs). Support level is normalized to 15 years.
Source: Adapted from Ragwitz et al. (2007) [16].

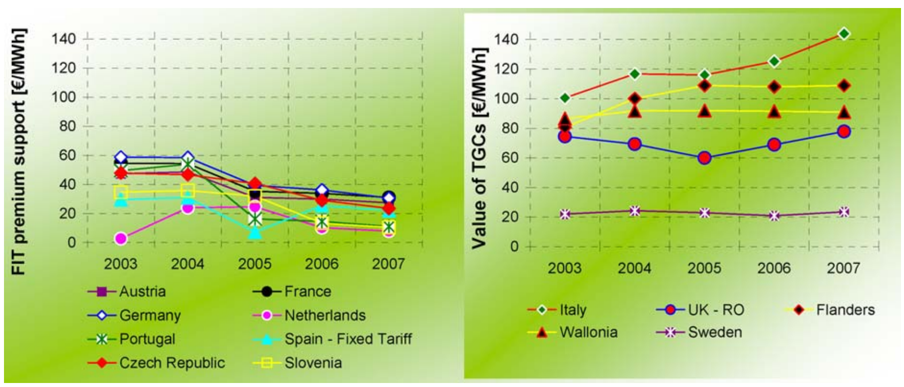


Fig. 46. Comparison of premium support level: FIT-premium support vs. value of TGCs. The FIT-premium support level consists of FIT minus the national average spot market electricity price.

Fig. 47. Effectiveness vs. net costs of promotion programs for electricity from RES in EU-27 countries (2005–2006).

age expected annuity of the renewable investment. The annuity calculates the specific discounted average return on every kWh produced by taking into account income and expenditure over the entire lifetime of a technology.

$$A = \frac{i}{(1-(1+i)^{-n})} \times \sum_{t=1}^{n} \frac{\text{Revenue}_t - \text{Expenses}_t}{(1+i)^t}$$

A = levelised profit; i = interest rate; t = year; n = technical lifetime.

The levelised profit resulting from wind energy investments has been calculated for Germany, Spain, Finland, France, Austria, Belgium, the Czech Republic, Ireland, Italy, Lithuania, Poland, Sweden and the UK based on the expected support level during the promotion period. For the five countries using quota obligation systems, the certificate prices of 2007 were extrapolated for the entire active period of the support.[18] Furthermore an interest rate of 6.5% was assumed. The annuity of the expected profit considers country-specific wind resources.

The correlation between the levelised profits resulting from investments and the effectiveness of the support instrument is shown in Fig. 47. This is done qualitatively by plotting the effec-

[18] This assumption may be questionable because certificate prices may relax as the certificate markets in those countries mature. However, the previous development of the certificate prices has generally not been characterised by significant price changes.

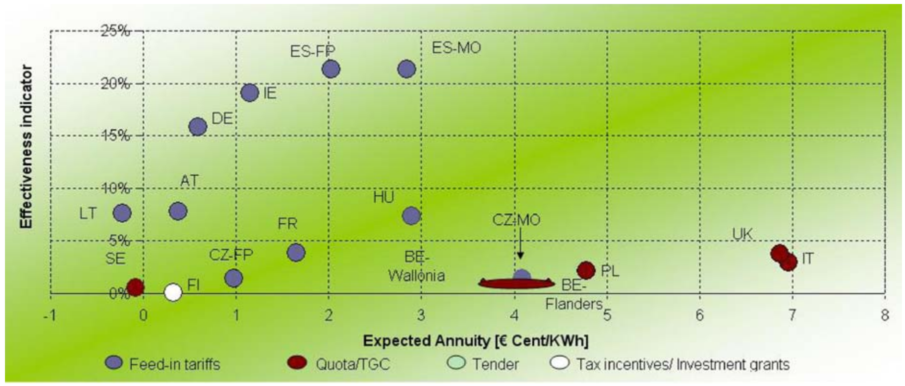


Fig. 48. Wind onshore: effectiveness indicator compared to the expected profit for the year 2006.
Source: Adapted from Ragwitz et al. (2007) [16].

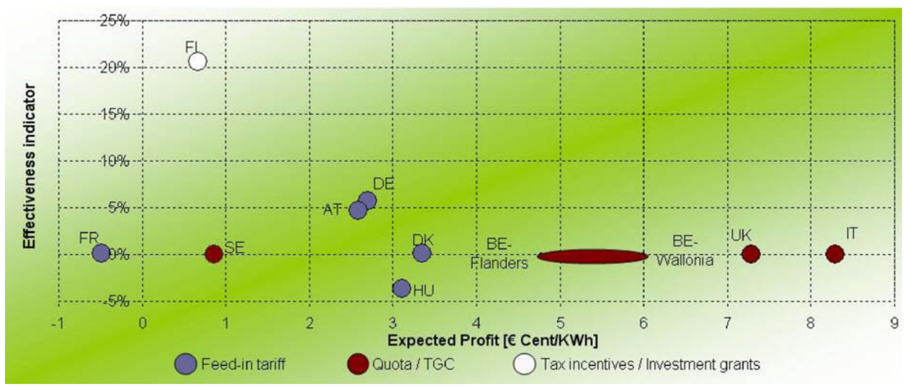


Fig. 49. Biomass forestry: effectiveness indicator compared to the expected profit for the year 2006.
Source: Adapted from Ragwitz et al. (2007) [16].

tiveness against the annuity in Fig. 48. It should be mentioned that Belgium has two different quota schemes, one in Walloon and the other in Flanders. Also, in Spain and in the Czech Republic, two different tariff options exist in parallel: a fixed price option and a market-oriented option with a feed-in-premium (Fig. 49).

Results for the example of onshore wind

- Generally the levelised profit and the effectiveness show a broad spectrum in quantitative terms for the countries under consideration. It should be pointed out that the different instruments have different levels of maturity and that policy schemes in some countries – in particular quota obligation systems – are still in a transitional phase.
- It is striking that the four countries – Italy, the UK, Poland and Belgium – which have transformed their markets into quota systems as the main support instrument have high levelised profits, but low growth rates. The high profit results in particular from the extrapolation of the presently observed certificate prices. Although this assumption is questionable, the results show that certificate systems can lead to high producer profits resulting from high investment risks. The only exemption from countries using quota obligation represents Sweden with a low profit and a low growth rate. This is due to the fact that quota systems tend to favour least cost renewable energy technologies such as biomass in Sweden.
- On the other hand countries with feed-in-tariffs seem to be typically more effective at generally moderate support levels. An exception to this rule is France, where strong administrative barriers are preventing a rapid development of wind energy.
- Spain achieved the highest growth rates in terms of the effectiveness indicator offering an adequate profit. The expected profit here is higher than in the other feed-in countries not because of a high support level, but rather because of the relatively low electricity generation costs due to good resource conditions on the one hand and low investment costs on the other.

Results for the example of onshore wind

- The same statement regarding the maturity of instruments as made for the case of wind on-shore holds for the case of biomass forestry.
- The biomass sector shows a much higher diversity compared to the case of wind on-shore, as regards the technologies and fuel sources used. Therefore it is more difficult to derive strong conclusions from the comparison of the different countries.
- It can still be observed that the highest support levels have been seen in the three countries applying quota systems as the main instrument, IT, UK and BE. Only Sweden shows a much lower level of the expected profit.
- Due to the fact that biomass is often used in form of co-firing of (sometimes imported) biomass the effectiveness indicator may show more drastic changes between different years (depending on the extent biomass is used as a fuel for co-firing). Therefore for some of the very highly effective countries like NL

Table 6
Summary of the specific relevant performance parameters.

	Period of time analysed	RES quantity deployed (W/cap yr)	Magnitude of absolute support level	Decrease in support over time?	Risk for investors	Other important aspects
FIT and premium						
Denmark	1992–1999	High	Low	No	Low	
Germany	1998–2005	High	Medium	Yes	Low	
Spain	2002–2005	High	Low (fixed option); medium (premium)	Yes	Low	
Austria	2002–2005	High	Medium	No	Low	Support level to high because of parallel investment subsidies
Portugal	2002–2005	High	Low	No	Low	
France	2002–2005	Low	Medium	No	Low	High administrative barriers
RPS and quota-based TGC						
UK (RO)	2003–2005	Low (quota not met)	High	Yes	Medium/high	Penalty too low
Italy	2003–2005		High	No	High	Time of validity of RES plants for certificates too low (8 years)
Sweden	2003–2005	High (quota met)	Low	Constant	Medium	Windfall profits due to some old capacities also qualifying for certificates
Belgium	2003–2005	Low (quota not met)	High	No	Medium/high	Low penalty, windfall profits due to some old capacities also qualifying for certificates
Tendering						
UK (NFFO)	1990–1998	Low	Low	Yes	Low after select	Capacities to low

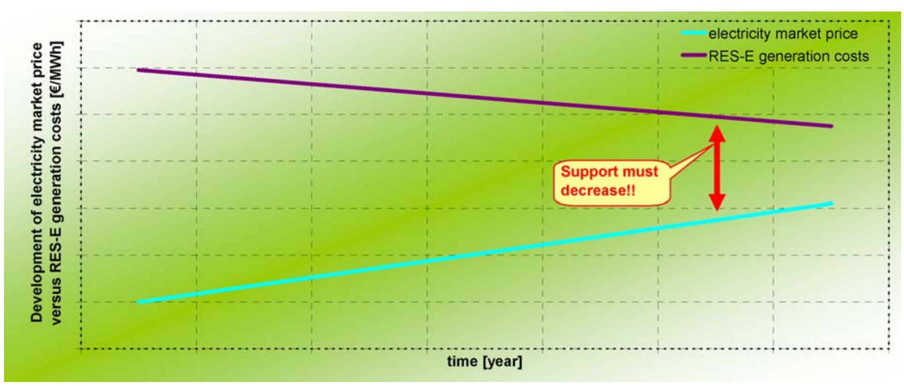


Fig. 50. The dynamics of RES-E costs and the development of conventional electricity market prices.

and BE a singular effect may be seen here. Also the negative effectiveness of FI is caused by such variations in the use of biomass.

As a general conclusion it can be stated that the investigated feed-in systems are effective at a relatively low producer profit. In contrast, it can be observed that the present quota systems only achieve rather low effectiveness at comparably high profit margins. We would like to emphasise that these quota systems are relatively new instruments in all the countries currently using them. Therefore the observed behaviour might still be characterised by significant transient effects.

7.4. Summary of historical RES policy performances

Several Member States have had introduced support schemes for electricity from RES for a long time period, whereas only some achieved considerable performance in terms of installed RES market penetration. An overview of selected strategies is given in Table 6.

8. Conclusions

The major general conclusions of this review are (see also Huber et al. [11], Held et al. [10], Ragwitz et al. [16], Haas et al. [7], Toke [17]):

- It is important for a promotional system to place a strong focus on new capacities and not mix existing and new capacities;
- The dissemination effectiveness of energy policy instruments depends significantly on the credibility of the system for potential investors. It must be guaranteed that the promotional strategy, regardless of which instrument is implemented, persists for a specified planning horizon. Otherwise the uncertainty for potential investors is too high and it is likely that no investments will take place at all.

- With respect to the investors' perspective, it is important to state that, at low risk (the case of FITs), the profitability expected is lower and, hence, so are the additional costs that are finally paid by consumers.

Regarding the comparison of the different support schemes, the investigated FIT systems are effective at relatively low additional costs for final customers. Thus, a well-designed (dynamic) FIT system provided a certain deployment of RES-E in the shortest time and at lowest costs for society. It is preferable to national green certificate trading schemes for three reasons: (a) they are easy to implement[19] and can be revised to account for new capacities in a very short time; (b) administration costs are usually lower than for implementing a national trading scheme. This fact is especially important for small countries where a competitive national trading scheme is difficult to implement; (c) a clear distinction is possible between the non-harmonised strategy for existing capacities (the stepped feed-in tariff) and the harmonised strategy (international trade) for new capacities. This is very important to avoid uncertainties and backlashes in transitional periods in which the framework conditions for new harmonised system could be negotiated. The most important design criteria for FITs are: (i) a carefully calculated starting value; (ii) a dynamic decrease of the FIT that takes learning into account; (iii) the implementation of a stepped and technology-specific tariff structure (see also Haas et al. [8]).

At present – with the exception of Sweden – quota-based TGC systems show a low effectiveness although comparably high profit margins are possible. However, beside the level of financial support, other market parameters such as investor's risk and technology specification play an important role in terms of effectiveness indicators of promotion strategies. Hence, it is difficult to imagine that a European-wide TGC market disconnected from the large incumbent generators would work more effective than on national level. Generally, the most important issues for the specific design of TGC-markets are a high penalty, the possibility of banking, a clear focus on new capacities and, to a certain extent, a technology-specific approach. With respect to Sweden the following aspects are important to be considered: The Swedish TGC system in the years 2002–2005 was actually a hybrid system. In addition to the certificate price it provided financial incentives for more expensive technologies like wind power, see e.g. van der Linden et al. [18]. Moreover, compared to virtually all other EU countries Sweden had and has the highest relative potential of cheap RES-E. Therefore, the Swedish cost resource curve of RES-E options is flat in the part relevant for determining the marginal costs within the RES-E quota. Moreover, in the period considered more certificates were issued than redeemed and to some extent old existing hydro capacity qualifies for the quota. So there was always some amount of certificates "banked" ensuring at least a minimum of competition in the market (No scarcity prices like e.g. in Belgium or the UK). However, most recently a general trend towards a technology specification of, assured by technology weighting factors for tradable green certificates has been noted in several Member States, as the UK or Romania. Hereby, novel and consequently more expensive technologies are eligible for more than on green certificate in order to cover their higher RES-E generation costs and hence stimulate a constant growth of all RES-E technologies.

Finally, a constantly discussed topic is whether a fully harmonised EU-wide promotion scheme should be pursued? Hereby the authors come to the common conclusion that currently a fully European-wide harmonised scheme cannot be recommended by any means. Or as Toke [17] puts it: "Problems begin to creep in when people start making proposals for the same incentives to be given anywhere in Europe. ... A harmonised EU-wide market-based system, would not improve cost-effectiveness, and may serve to reduce, rather than increase, local investment in renewable energy". However, we also have to bear in mind what happens in the mid-term (after the first wave of investments comes to the end of their depreciation periods). In the light of the dynamic development in the RES-E market (e.g. wind turbine manufacturers, biomass plant developers, photovoltaic system component producers) and in the conventional electricity market (increasing prices due to rising demand and capacities becoming scarce, highly volatile natural gas prices and highly volatile prices for CO_2-emission certificates), it is of course necessary to improve and further develop the promotion schemes for RES-E. The dynamics of RES-E costs and the development of conventional electricity market is depicted in Fig. 50.

Currently, competition exists between the different types of promotion scheme. This should lead to a future development in which the best elements of the different promotion schemes are established and the different systems then gradually converge into an optimal strategy consisting of these best features. Of course, the most important accompanying features of this process are continuity of development as well as adequate credibility for investors. Joint efforts for similar framework conditions such as, e.g. depreciation times, could be a first step in this direction. In other words, the validity of certificates and the duration period for which a FIT is guaranteed should eventually be the same in each country. Furthermore, joint initiatives or lessons-learned clusters for the several categories of instruments could contribute to significant progress in designing the promotion instruments. Such an initiative has already been started for FITs by the Spanish, German and Slovenian governments (The International Feed-In Cooperation – IFIC). We believe such an approach would be very important for quota-based TGC systems as well and an important step towards a more efficient and effective promotion of RES-E in the future.

References

[1] Butler L, Neuhoff K. Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. Working Paper, University of Cambridge, United Kingdom; 2004.
[2] Connor PM. UK renewable energy policy. Renewable & Sustainable Energy Reviews 2003;7:65–82.
[3] Dinica V. Support systems for the diffusion of renewable energy technologies—an investor perspective. Energy Policy 2006;34(4):461–80.
[4] European Commission [EC]. Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market; 2001.
[5] European Commission. European Commission in the Directive on the promotion of the use of energy from renewable sources (COM(2008) 19); 2008.
[6] Haas R, editor, Faber T, Green J, Gual M, Huber C, Resch G. Promotion Strategies for Electricity from Renewable Energy Sources in EU Countries, Review-report of the project ELGREEN, TU Wien; 2001.
[7] Haas R, Meyer NI, Held A, Finon D, Lorenzoni A, Wiser R, et al. Promoting electricity from renewable energy sources—lessons learned from the EU, U.S. and Japan. In: Sioshansi FP, editor. Electricity market reforms. Elsevier Publishers; 2007.
[8] Haas R, Eichhammer W, Huber C, Langniss O, Lorenzoni A, Madlener R, et al. How to promote renewable energy systems successfully and effectively. Energy Policy 2004;32(6):833–9.
[9] Harmelink M, Voogt M, Cremer C. Analysing the effectiveness of renewable energy supporting policies in the European Union. Energy Policy 2006;34(3):343–51.
[10] Held A, Haas R, Ragwitz M. On the success of policy strategies for the promotion of electricity from renewable energy sources in the EU. Energy & Environment 2006;17(6):849–68.
[11] Huber C, Faber T, Haas R, Resch G, Green J, Ölz S, et al. Action plan for deriving dynamic RES-E policies—report of the project Green-X; 2004. Available at: www.green-x.at.
[12] Lemming J. Financial risks for green electricity investors and producers in a tradable green certificate market. Energy Policy 2003;31:21–32.
[13] Meyer NI. European schemes for promoting renewables in liberalised markets. Energy Policy 2003;31(7):665–76.

[19] Of course, this requires an understanding of the marginal costs of the various technologies and a follow-up of the individual plants.

[14] Meyer NI. Learning from wind energy policy in the EU: lessons from Denmark, Sweden and Spain. In: European Environment; forthcoming.
[15] Mitchell C, Bauknecht D, Connor PM. Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. Energy Policy 2006;34(3):297–305.
[16] Ragwitz M, Held A, Sensfuss F, Huber C, Resch G, Faber T, et al. OPTRES—assessment and optimisation of renewable support schemes in the European electricity market; 2006.
[17] Toke D. Renewable financial support systems and cost-effectiveness. Journal of Cleaner Production 2007;15:280–7.
[18] van der Linden NH, Uyterlinde MA, Vrolijk L, Nilsson J, Khan K, Astrand K, et al. Review of international experience with renewable energy obligation support mechanisms. Netherlands: Petten; 2005. ECN-C-05-025.
[19] Verbruggen A. Tradable Green Certificates in Flanders (Belgium). Energy Policy 2004;32:165–76.
[20] Wene CO. Experience curve for energy technology policy. Paris: OECD/IEA; 2000. p. 28.